Impacts of Water Level Fluctuations on Kokanee Reproduction in Flathead Lake

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IMPACTS OF WATER LEVEL FLUCTUATIONS
ON
KOKANEE REPRODUCTION IN FLATHEAD LAKE

Annual Progress Report
FY 1985

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EXECUTIVE SUMMARY

This study has investigated the effects of the operation of Kerr Dam on the reproductive success of kokanee that spawn along the shores of Flathead Lake. We have estimated the spawning escapement to the lakeshore, characterized spawning habitat, monitored egg and alevin survival in redds, and related survival to length of redd exposure due to lake drawdown. Groundwater discharge apparently attracts kokanee to spawning sites along the lakeshore and is responsible for prolonging egg survival in redds above minimum pool. We have quantified and described the effect of lake drawdown on groundwater flux in spawning areas. This report defines optimal lakeshore spawning habitat and discusses egg and alevin survival both in and below the varial zone.

We counted 1,134 redds at 19 areas around Flathead Lake in 1984. The majority (95%) of the redds were along the east shore, as in previous years of the study. Spawning had not previously been observed in four of these areas. An additional 750-1,000 kokanee spawned in the Swan River, though spawning habitat below Bigfork Dam is limited. Timing of the run was similar to the past four years, with lakeshore spawning beginning at the end of October and peaking at the end of November.

Spawners were primarily (78%) age III+, with age II+ and IV+ comprising 18% and 4% of the run, respectively. The mean size of female spawners was 356 mm. the average length of spawners (males and females combined has varied from 330 mm to 370 mm over the past 10 years. This variation is attributable to shifts in the age composition of spawning fish and to density dependent variation in growth.

Sixty-two percent of the redds we observed were in shallow beach sites, in the zone exposed by drawdown. However, significant numbers of redds were built below minimum pool at Gravel Bay (310), Blue Bay (30), Woods Bay (32), Pineglen (12) and Dr. Richards Bay (17). Recruitment from lakeshore redds may be largely dependent on those redds built below minimum pool.

We calculated the fredle index from measurements taken on photographs to characterize the size composition of spawning substrate. The mean value of the index at the different spawning areas varied from 7.2 to 16.6. Index values above 5.0 characterize high quality salmonid spawning habitat.

Groundwater flux (discharge/area) in spawning sites was between 0.1 and 0.4 cm/hour in 77% of the redds sampled. Values above 1.0 cm/hour were measured in shallow redds, but use of the seepage meter may be invalid in this wave-influenced zone. Groundwater discharge through redds provides dissolved oxygen and

metabolic waste disposal to incubating eggs. The dissolved oxygen content of groundwater flowing through redds varied between 8.0 and 11.0 mg/l in 73% of redds. Dissolved oxygen in the substrate of deep redds, from 8 to 20 feet below minimum pool elevation, was not critically low.

The changes in groundwater table elevation and discharge during lake drawdown are influenced by recharge rates and the hydraulic conductivity of shoreline aquifers. Egg survival is enhanced in exposed redds where an elevated groundwater table or active seeps maintain wetted gravel. A numerical model of the change in groundwater stage during drawdown at one site in Skidoo Bay has enabled us to predict length of exposure of redds at any elevation. Given the exposure tolerance of eggs, it is possible to predict mortality in redds based on their elevation.

Kokanee eggs in redds exposed by lake drawdown did not survive unless they were wetted by groundwater. For this reason egg survival varied widely at all spawning areas. Experiments with artificially planted eggs showed that eyed eggs resist desiccation in damp gravel for 50 to 90 days. At groundwater influenced sites, such as Pineglen and Orange House in Skidoo Bay, egg survival ranged from 80 to 100% in redds between 2,883 and 2,885 feet. Live alevins were seen in the gravel in April. At sites subject to substrate transport and those not enhanced by groundwater, egg survival was 0 to 4% after exposure longer than one month. Woods Bay West and Dr. Richards North typify these sites.

We also monitored emergence from redds below minimum pool at Gravel and Blue Bay. We estimated 20% egg-to-fry survival at Gravel Bay. Survival was inexplicably low (0%) at Blue Bay. Successful emergence from exposed redds occurred where groundwater discharge saturated the substrate . We measured the ability of kokanee sac-fry to move through saturated gravel in experimental channels. Fry moved 60-120 cm in four days, depending on the substrate size composition.

We seined and tagged age II+ and III+ kokanee in late spring in Skidoo Bay to determine what stocks compose the winter fishery there. A large aggregation of fish was present in Skidoo Bay throughout the winter of 1984-85, and was subject to an intensive ice fishery. Some fish moved into Big Arm Bay in the early summer, staying until rising summer water temperatures triggered them to move into the central lake basin. Tags returned during the summer fishery show a northward movement of fish through June and July. Fishing concentrates between Bigfork and Woods Bay in August, and so a large number of marked fish were recovered in that area. Marked fish were also recovered at eleven spawning areas in the Flathead River, its tributaries, and around the lakeshore. One hundred seventeen marked fish were found in

McDonald Creek, a tributary of the Middle Fork of the Flathead River; eleven were observed in the South Fork below Hungry Horse Dam, and ten in the main stem of the river. It is apparent that the Skidoo Bay aggregation is composed of diverse spawning "stocks". Weak stocks, e.g. lakeshore spawners, may be over-exploited by the intensive winter fishery.

We estimated the abundance of four zooplankton species, which constitute the principle diet of kokanee, from April through October, 1984, by sampling a single index station monthly. Total zooplankton density was similar to previous years. The average density of *Daphnia thorata* increased slightly from 1983 to 1984. The densities of *Diaptomus*, *Epischura*, and *Leptodora* were lower than in the previous three years. Changes in the zooplankton community may reflect increased grazing pressure from opossum shrimp (*Mysis relicta*).

Fluctuations in average density may reflect the annual variability in lake productivity as much as increased grazing pressure. Circumstantial evidence suggests that Mysid shrimp have selectively reduced the density of cladocerans in other lakes.

Though monitoring of lakeshore spawning will continue through completion of the study, principle spawning areas have been defined. We have measured the tolerance of kokanee eggs to exposure, both experimentally and in natural redds. We have characterized spawning sites in terms of substrate size, groundwater discharge, and dissolved oxygen. Given a range of these parameters that defines high quality habitat, we will quantify the extent of un-used habitat, particularly in historic spawning areas. Spawner returns to these areas have been lost because of egg mortality associated with drawdown. Methods to mitigate these losses to the lakeshore spawning stock will be developed and evaluated.

ACKNOWLEDGMENTS

A number of people have helped me to assume leadership of the lake kokanee study. My sincere thanks to John Fraley, Pat Clancey, and Janet Decker-Hess. Our field crew, Rick Adams, Jon Cavigli and Greg Smith, provided insight and expertise in sampling design and data analysis. I appreciate, also, the ready advice of Jim Vashro, Laney Hanzel and Scott Rumsey on kokanee biology, Flathead Lake fisheries, and revision of this report. My thanks, also, to Stewart Kienow for his assistance with experiments at the Somers Hatchery. Jim Darling, biologist for the Confederated Salish and Kootenai Tribes, edited the report and clarified the discussion. Jean Blair and Dennice Grigg typed the manuscript. This study was funded by the Bonneville Power Administration.

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INTRODUCTION

Flathead Lake is a large oligomesotrophic lake located in northwestern Montana (Stanford et al., 1981). It has the greatest surface area (476.6 km^2) of any natural freshwater lake west of the Mississippi River. The lake has a maximum length of 43.9 km and a maximum breadth of 24.9 km. Its mean depth is 32.5 m with a maximum depth of 113 m located near Yellow Bay (Potter 1978). The 199.1 km shoreline of the lake is characterized by numerous protected bays and inlets with gravel and cobble beaches. Approximately 50% of the shoreline substrate is composed of gravel and cobble (Figure 1). Sand and finer silts are generally restricted to the north and south end of the lake and compose 17% of the shoreline. The remaining 33% of the shoreline is characterized by steep cliffs and exposed bedrock.

Permanent and summer homes are found along the entire shoreline of Flathead Lake. Larger population centers are located at Polson, Somers, Lakeside and Bigfork. Moderate air temperatures, created by the buffering capacity of a large lake, allows cherry production on much of the land adjacent to the east shore. Agricultural production including cattle, sheep, grain and hay is restricted primarily to the southern and northern ends.

Kerr Dam, located 7 km downstream of the natural lake outlet, was closed in April 1938. A license was issued to Rocky Mountain Power Company, a subsidiary to Montana Power Company (MPC), on May 23, 1930 (MPC 1976). The license was transferred to MPC on August 8, 1938 after the closing of the dam. The first generating unit of 56,000 kilowatts (KW) was placed into commercial operation on May 20, 1939. A second generating unit of the same capacity was installed and placed into operation in May 1949. These two units utilized the natural flow of the Flathead River and the approximately 1,217,000 acre-feet of storage created in Flathead Lake by Kerr Dam. Following the filling of the Hungry Horse Reservoir in 1953, MPC installed a third 56,000 KW generating unit in December 1954. A 1984 ruling by the Federal Energy Regulatory Commission has determined that ownership of the dam will be shared between MPC and the Confederated Salish and Kootenai Tribes.

Prior to impoundment by Kerr Dam, water levels for Flathead Lake remained near 2,882 feet from September to mid-April. Spring runoff increased the elevation to the maximum for the year (2,893 feet) in May and June. Since impoundment, maximum lake elevation of 2,893 feet has been reached in June and maintained into September (Figure 2). Drawdown usually begins in mid-September. Flood control and recreational constraints on the project require an elevation of 2,883 feet be drafted by April 15, an elevation of 2,890 feet be reached by May 30 and maximum pool level maintained through Labor Day (Montana Power Company 1976). When the lake stage reaches 2,886 feet during a flood, operation requires the gates to be open and lake elevation to not exceed

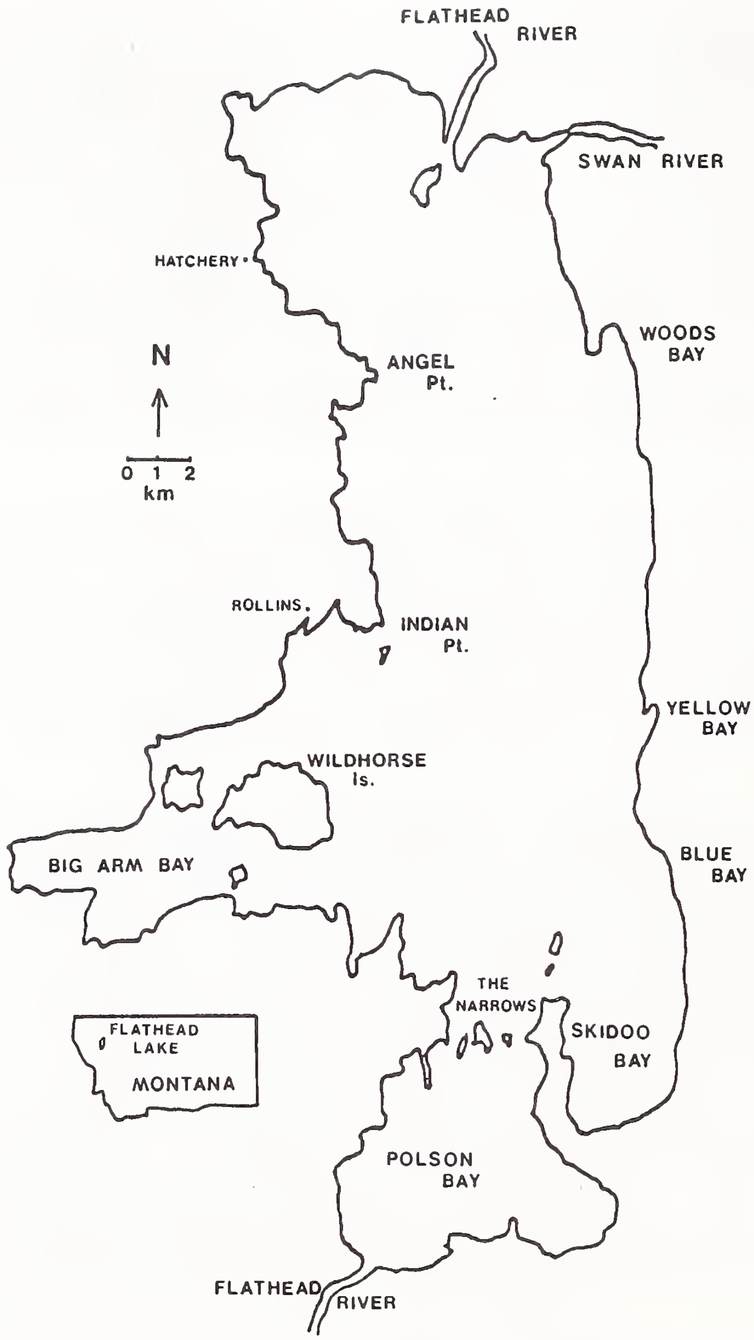


Figure 1. Map of Flathead Lake

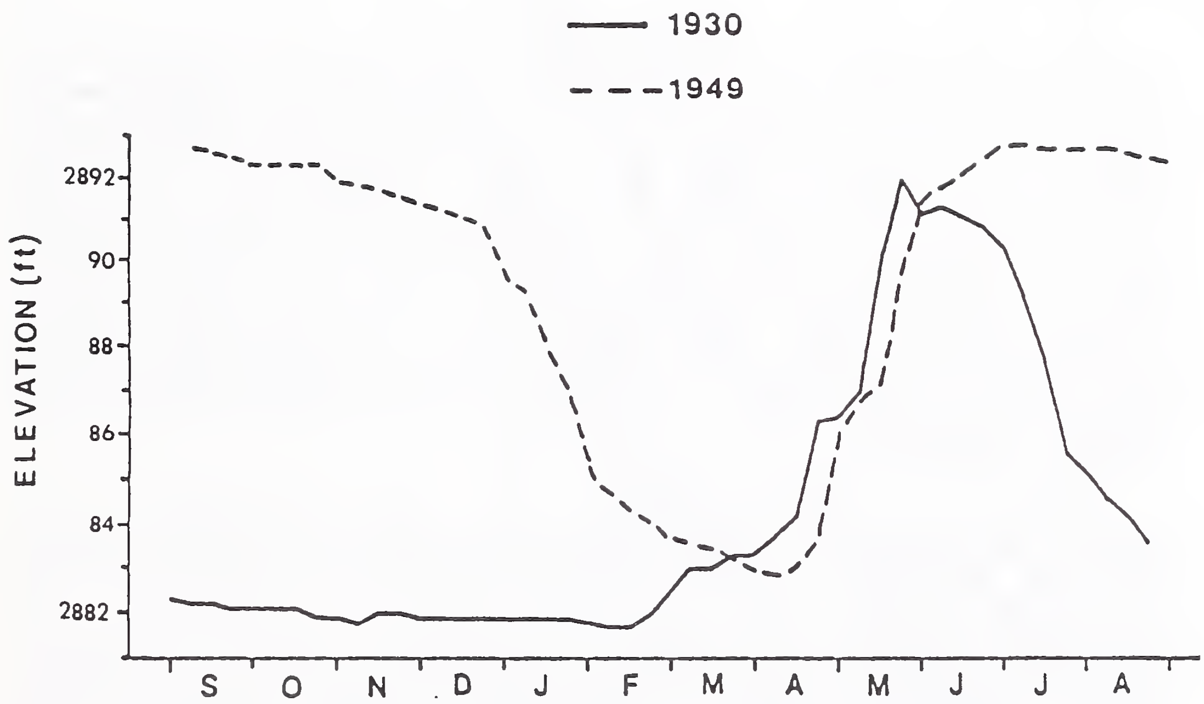


Figure 2. A comparison of the annual change in the elevation of Flathead Lake before and after the construction of Kerr Dam in 1937.

2,893 feet Natural channel restrictions allow a maximum outflow of 55,000 cfs when lake stage is 2,893 feet but only an outflow of 5,200 cfs when lake stage is at minimum pool of 2,883 feet (Graham et al., 1981).

Kerr Dam provides the bulk of MPC's system load frequency control. It provides 180,000 KW of peak capacity and 119,000 KW of critical period energy (MPC, 1976). The system load typically has a winter peak (occurring generally in December and January) with a one-to-two hour peak during the evening hours ending at 6:00 or 7:00 p.m. During times of excess water, the dam is operated essentially for baseload. When the river is controllable, Kerr is used for both baseload (at a lower level) and peaking.

Two tributaries in the Flathead drainage, the South Fork of the Flathead River and Swan River, are presently regulated by hydroelectric facilities (Figure 3). The Swan River diversion at Bigfork was built in 1902 with a generating capacity of 4,150 KW (Graham et al. 1981). Hungry Horse Dam, located on the South Fork Flathead River 8.5 km above its confluence with the main river, was closed in September 1951. Hungry Horse has a capacity to generate 328,000 KW, regulating one-third of the drainage area to Flathead Lake. The electrical energy from the Hungry Horse project is marketed by the Bonneville Power Administration (BPA). The dam is operated primarily for flood control and hydroelectric energy production.

Kokanee salmon (Oncorhynchus nerka), the land-locked form of sockeye salmon, were originally introduced to Flathead Lake in 1916. By 1933, kokanee had become established in the lake and provided a popular summer trolling fishery as well as a fall snagging fishery in shoreline areas (Alvord, 1975). Presently, Flathead Lake supports the second highest fishing pressure of any lake or reservoir in Montana (Montana Department of Fish and Game, 1976). Kokanee salmon constitute the largest fishery in Flathead Lake and the upper Flathead River (Robbins, 1966; Hanzel, 1977; Fredenberg and Graham, 1982; and Graham and Fredenberg, 1982). A creel census conducted in 1981-82 on the lake and upper drainage estimated fishing effort to be 204,732 fisherman-days per year (Fredenberg and Graham, 1982; and Graham and Fredenberg, 1982). Kokanee represented 80 and 92% of the catch in the river and lake, respectively. Kokanee were captured by several angler methods including summer boat trolling, fall shoreline snagging and a localized winter hand-line fishery. Kokanee also provided forage for bull trout seasonally and year round for lake trout (Leathe and Graham, 1982).

Kokanee salmon mature in Flathead Lake then return to various natal grounds to spawn. Spawning in the Flathead system usually occurs at the end of the fourth growing season. Spawning along Flathead Lake shoreline areas was first documented in the 1930's (Alvord, 1975). Thirty shoreline spawning areas were documented

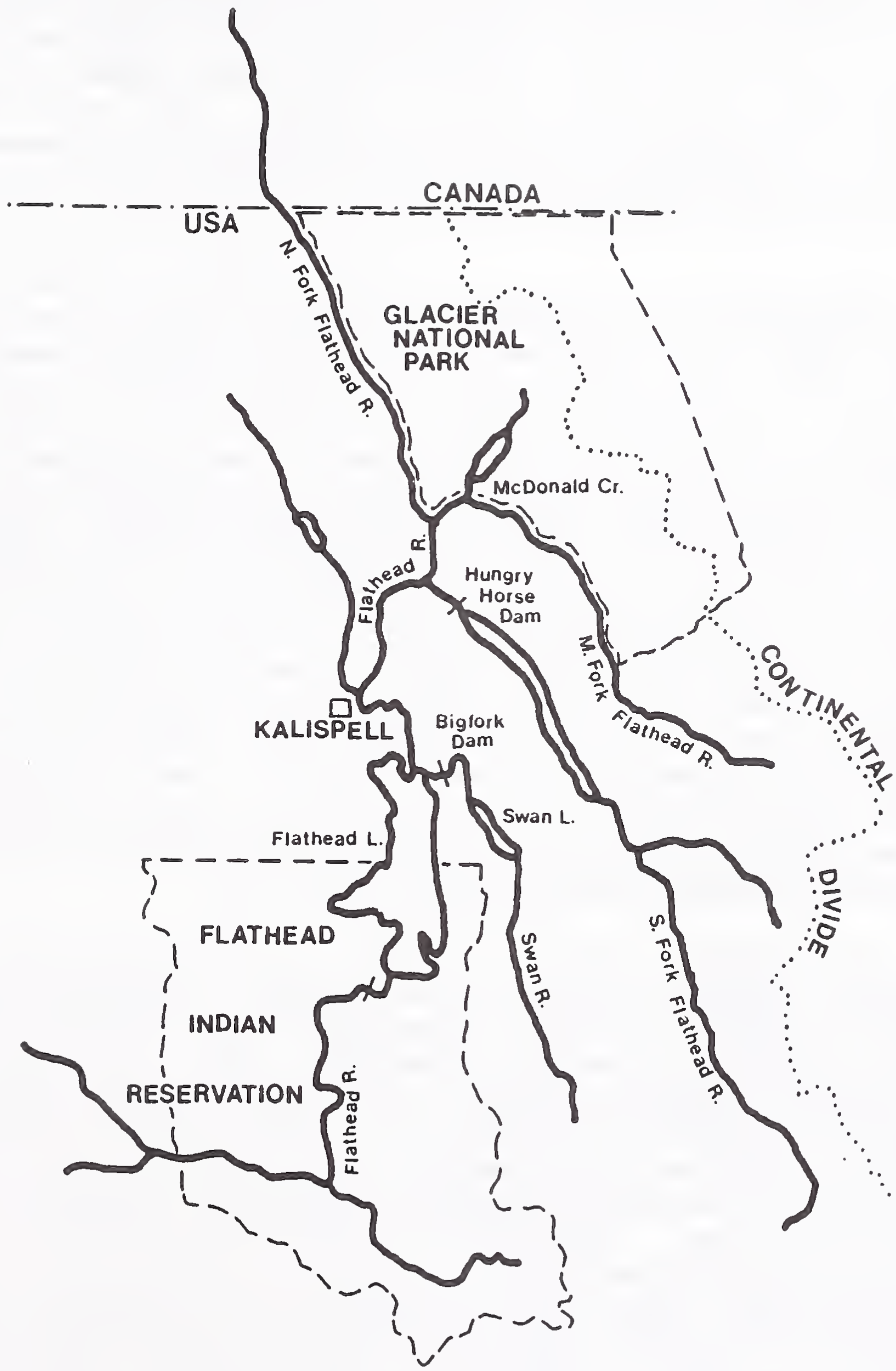


Figure 3. Map of the Flathead river drainage.

in the early 50's. Kokanee were seined from shoreline areas in 1933 and 21,000 cans of fish were processed and packed for distribution to the needy. Kokanee were first observed spawning in McDonald Creek in the 1930's and the Whitefish and Flathead rivers in the late 40's and early 50's (Stefanich, 1953). Because of increased winter water temperatures in the main Flathead River after the construction of Hungry Horse Dam, a substantial spawning run began to develop in the main river and below the dam in the South Fork during the early 50's (Hanzel, 1964; and Graham et al., 1980). Presently, kokanee are utilizing all of these areas as well as the Middle Fork Flathead River, its tributaries and the Swan River below Bigfork Dam.

The operation of Kerr Dam, located below Flathead Lake on the Flathead River, has altered seasonal fluctuations of Flathead Lake. Lake levels presently remain high during kokanee spawning in November and decline during the incubation and emergence periods. Groundwater plays an important role in embryo and fry survival in shoreline redds exposed by lake drawdown. Stefanich (1954) and Domrose (1968) found live eggs and fry only in shoreline spawning areas wetted by groundwater seeps. Recent studies have revealed that operation of Hungry Horse Dam severely impacted successful kokanee spawning and incubation in the Flathead River above Flathead Lake (Graham et al., 1980; McMullin and Graham, 1981; Fraley and Graham, 1982; Fraley and McMullin, 1983; and Fraley, 1984). Flows from Hungry Horse Dam to enhance kokanee reproduction in the river system were voluntarily met by the Bureau of Reclamation in 1980 and 1981. Flows recommended by the Department of Fish, Wildlife, and Parks through the Northwest Power Planning Council have been provided by the Bureau and Bonneville Power Administration since 1982.

In lakeshore spawning areas in other Pacific Northwest systems, spawning habitat for kokanee and sockeye salmon was characterized by seepage or groundwater flow where suitable substrate composition existed (Foerster, 1968). Spawning primarily occurred in shallower depths (<6 m) where gravels were cleaned by wave action (Hassemer and Rieman, 1979 and 1980; Stober et al., 1979a). Seasonal drawdown of reservoirs can adversely affect survival of incubating kokanee eggs and fry spawned in shallow shoreline areas. Jeppson (1955 and 1960) and Whitt (1957) estimated 10-75 percent kokanee egg loss in shoreline areas of Pend Oreille Lake, Idaho after regulation of the upper three meters occurred in 1952 by Albeni Falls Dam. Bowler (1979) found lower spawning escapement, and fewer shoreline areas used for spawning on Lake Pend Oreille after 20 years of dam operation. In studies on Priest Lake, Idaho, Bjornn (1957) attributed frozen eggs and stranded fry to winter fluctuations of the upper three meters of the lake. Eggs and fry frozen during winter drawdown accounted for a 90% loss of shoreline spawning kokanee in Donner Lake, California (Kimsey, 1951). Stober et al. (1979a) determined that irrigation drawdown of Banks Lake, Washington reduced shoreline survival during five of the seven years the system was studied.

Within the larger context of describing the effects of the operation of Kerr Dam on kokanee reproductive success, the goals of the study in 1984-85 were:

1. To quantify lakeshore spawning on Flathead Lake and in the Swan River, and further document the effects of drawdown exposure on egg/alevin mortality.

2. To characterize spawning habitat, both above and below minimum pool, by quantifying elevation, substrate composition, and the flux and dissolved oxygen content of groundwater in kokanee redds.

3. To further describe the effects of dam operation on the groundwater regime in spawning areas, and their influence on egg/alevin survival.

4. To monitor emergence of fry from redds below minimum pool, and test the ability of fry to move through substrate to the lake from exposed redds wetted by groundwater.

METHODS

SPAWNER COUNTS AND SPAWNING SITE INVENTORY

Potential shoreline spawning areas around Flathead Lake were surveyed weekly by boat, and once by air, between November 7 and December 20, 1984. The eastern shore from Woods Bay (Fig. 1) to Skidoo Bay was surveyed eight times. Effort on the west shore was concentrated in Big Arm Bay, Crescent Bay, Angel Point to Table Bay, Lakeside Bay and Somers Bay. These areas were all important spawning areas in past years. Surveyed shoreline totalled approximately 90 miles. The Swan River, below the diversion dam and at the Bigfork powerhouse, was surveyed ten times, beginning September 14. Shoreline areas characterized by extreme gradient, bedrock outcroppings, and boulder or muddy substrate were not considered potential spawning habitat. For example, the northern shore from Somers to Bigfork and some areas of Polson Bay were excluded from the survey.

Where concentrations of spawning fish were observed, redds and fish were counted by SCUBA divers or from a boat. At twelve principle spawning areas on Flathead Lake, and at a single area on Swan and Ashley Lakes, we marked representative redds with numbered rebar stakes. At each of these areas substrate adjacent to spawning sites where no redds were excavated, were marked in similar fashion and designated "non-redd" sites.

Sex, age, and size of spawners were determined in gill-netted samples from eight east shore sites: Woods Bay, Dr. Richards Bay, Thurstons (Skidoo Bay V), Pineglen, Gravel Bay, Blue Bay, Dee Creek, and at Hatchery Bay (Somers) on the west shore.

CHARACTERIZATION OF SPAWNING HABITAT

We measured the elevation at marked redd sites with a stadia rod and level, using the lake elevation obtained from Kerr Dam Operations for reference. At Blue and Gravel Bays, where redds were distributed across a wide depth interval below minimum pool, we estimated redd elevation with a depth gauge while swimming underwater transects.

The size composition of the substrate in redd and non-redd sites was determined by photographing the site with a Nikonos 35mm underwater camera, and measuring the particle size at 50 to 100 grid points on the resulting projected slide. Each photograph, taken with high speed Ektachrome film without a strobe, included a 0.5 meter square metal frame and meter stick for scaling. The scale of the projected slide could be adjusted with a zoom lens to actual size. Particles at the grid points were classified into four sizes: less than 6 mm, 6-16 mm, 16-50 mm, and greater than 50 mm. The percent of material in each grain size class was

calculated by averaging the results of two readings from the same slide. We calculated the cumulative percentage of material up to each size class, and regressed the natural logarithm of the particle size (the upper limit of each size class) on the inverse probability transform of the cumulative percentage. If a straight line fit the data well ($r > 0.90$) we assumed that grain sizes were log normally distributed.

We chose the fredle index (Shirazi and Seim, 1979), a single-variable descriptor of particle size distribution to characterize lakebed substrate in spawning areas. The index is a ratio of mean particle size, which is directly proportional to pore size and permeability, and the sorting coefficient, which is inversely proportional to permeability. It is calculated by:

$$f_i = d_g/s_o$$

where: $d_g = (d_{84} \times d_{16})^{1/2}$

$s_o = (d_{75}/d_{25})^{1/2}$ and

d_n = particle size that n percent of the substrate is smaller than.

Our photo analysis classified grains into four size classes. The conventional use of 7-9 screen sizes probably yields more accurate results. This ratio varies directly with permeability, which influences groundwater flux and how lake water is exchanged with interstitial water in the substrate. Egg survival depends on exchange of water in the substrate to supply dissolved oxygen and carry away metabolic waste.

To compare the results of photographic substrate analysis with the more conventional sieve analysis, we sampled six sites using both methods. Cores were excavated into a 20 liter bucket, dried, and shaken through a set of six sieves (0.063, 2, 6.35, 16, 50.6, and 76.2 mm). Material retained in each sieve was weighed to the nearest gram. Geometric mean grain size and fredle index were calculated as above.

We measured vertical groundwater discharge through the lakebed with seepage meters (Lee and Cherry, 1978). These meters consist of the top nine inches of a steel 55 gallon drum. The discharge port is fitted with a rubber stopper and a 6 inch length of 1/4 inch plastic tubing. Seepage meters were worked into the lakebed until a seal was effected and allowed to equilibrate for several hours before seepage was collected in evacuated plastic bags over a known interval of time. As the lake was drawn down, onshore groundwater stage was monitored in sandpoint wells driven into the gravel. Sandpoints are 5 foot lengths of 1 1/2 inch I.D. pipe fitted with steel driving points (Campbell Mfg., Bechtelsville, PA). Screened perforations in the lower 15 inches of the sandpoint allow inflow of groundwater (Decker-Hess and

McMullin, 1983). These sandpoints also allow measurement of hydraulic conductivity, using a pump test (Woessner and Brick, 1983). Three sandpoints were installed at twelve sites: Stoner Creek (Lakeside), Table Bay, Deep Bay, Big Arm on the west shore, and Yellow Bay, Blue Bay, Gravel Bay, Pineglen, Orange House (Skidoo II), and Thurstons (Skidoo V) on the east shore. Water table elevations were measured biweekly from January 15 through May 30, 1985. Pump tests to estimate hydraulic conductivity were replicated twice during that interval (see Appendix D). Hydraulic conductivity calculations followed the methods of Woessner and Brick (1983). Groundwater flux, or apparent velocity, was measured directly by seepage meters, or calculated from measurements of hydraulic slope and conductivity from sandpoint wells.

Calculations were based on the Darcy equation:

$Q = KiA$ where Q is discharge
K is hydraulic conductivity
i is hydraulic slope
A is cross sectional area of the aquifer

The concentration of dissolved oxygen in groundwater was measured by Winkler titrations of samples collected in the seepage meters or by pumping sandpoint wells with a hand-driven peristaltic (Jackrabbit) pump.

Groundwater samples from nine spawning areas were assayed by the Water Chemistry Laboratory at the University of Montana. They measured the concentration of four cations (Na, K, Ca, Mg), two anions (SO_4, Cl), bicarbonate, phosphate, total dissolved solids, and pH. Sampling was replicated at seven sites to examine variability in water quality over time. Conductivity was calculated from ion balance. Samples for these assays were drawn into 250 ml. poly bottles, and shipped on ice to the laboratory.

EGG AND ALEVIN SURVIVAL

From January 10 to April 30, 1985 we monitored egg development and embryo survival in 37 marked redds exposed by drawdown. We excavated redd sites carefully, using hand tools, until pockets of eggs or sac-fry were found. Numbers of live and dead eggs and fry were counted, and their development noted. Any live eggs or alevins were returned to the substrate and buried. Position and depth of the eggs and fry relative to the groundwater table were recorded. Random excavation of unmarked sites contributed additional survival data. We planted fertilized green eggs in mesh bags containing coarse gravel at Swan River, Table Bay, and Dr. Richards Bay. At the two lakeshore sites, three lines of egg bags, with 50 eggs in each bag, were placed at 2,884, 2,886, and 2,888 feet. Intragravel temperature was monitored at each site by Taylor multi-probe thermograph (Model 5-062408). Bags from each

line were opened at monthly intervals to check development and survival.

We monitored fry emerging from redds below minimum pool at weekly intervals, from March 27 until June 21 at Blue Bay, and from April 12 until July 7 at Gravel Bay. We placed conical aluminum emergence traps (Stober et al, 1979) over ten redds at Blue Bay and 19 redds at Gravel Bay. These redds were selected to represent the range of depths at which spawning occurred. We placed four traps over each of four redds at Gravel Bay, one from each five foot interval of depth, to check trapping efficiency. When weekly trap catches from any trap exceeded 20 fry, 10 were preserved in 10% formalin for assessment of their condition ($k = \text{weight} \times 10^5/\text{length}^3$).

Total emergence, in each depth zone, was estimated by multiplying the average catch per trap by the number of traps required to cover an entire redd and the number of redds in each zone. Decker-Hess and Clancey (1984) found the area of an average redd to be 2.65 m^2, so that 10 traps, each covering 0.25 m^2, would be required to catch all emergent fry. To estimate total potential egg deposition, we multiplied fecundity (number of eggs per female) by the peak redd count and assumed that only one female spawned in each redd. At higher density spawning areas in the Flathead River the number of females per redd has been estimated to be 2.1 (Fraley and Graham, 1982) Fecundity was estimated from a regression of length on fecundity (Appendix Fig. A-3; Fraley, unpublished data). Fecundity at Gravel Bay where average female length was 372 mm, was estimated at 1,040 eggs.

The ability of emergent kokanee fry to migrate through substrate of varying size composition was tested in experiments at the Somers Hatchery. Evidence of this ability would imply that fry could reach the lake from redds exposed by drawdown, if sufficient groundwater flows were present to allow overwinter survival, hatching, and intragravel movement. Five 4.3x0.3x0.3 meter fiberglass troughs were filled with various mixtures of sand (fines) and gravel/cobble. Two troughs were filled with a mixture of 10% fines, and one each with 20%, 30%, and 40% fines respectively. The mixtures were verified by drying and sieving a sample of each trough. The troughs were installed in the ground at a slight gradient, and plumbed for supply and drainage on the hatchery system. Inflow was set at 2 liters/minute, and standpipes set into the drains so that a greater cross-section of the trough was kept wetted. Supply water flowed into the base of the trough, along its length, through a hose perforated at 6" intervals. These troughs simulated the groundwater seeps found at spawning areas on the shore of Flathead Lake.

Once stable flows were established in the troughs, 100 kokanee sac-fry were placed in Whitlock-Vibert boxes with coarse substrate, and buried in the wetted zone at the midpoint of each trough. Each of two experiments proceeded for four days, then the

flow was stopped and the troughs allowed to drain. Each trough was then excavated carefully from the downstream end, and the location of each fry was measured. Between the two experiments the substrate was re-mixed in each trough.

ZOOPLANKTON ABUNDANCE SAMPLING

We sampled the zooplankton community of Flathead Lake from April 15 to October 15, 1984, making replicate biweekly 15 m to surface tows at Station 2-4, 0.5 miles west of Wayfarer Point. We used a 0.5 meter Wisconsin net of 80 micron Nitex mesh, equipped with a General Oceanics 2030 flowmeter. The net was retrieved at 1 meter/second while maintaining position to keep the tow vertical. Hauls were preserved in 4% formalin with 40 g/l sucrose. The temperature structure of the water column was recorded with a thermocouple probe, and a Secchi disk reading was taken at the time of each zooplankton sample. Subsamples of each tow were examined in a Sedgwick Rafter cell, under a stereo microscope. Copepod and cladoceran crustaceans were identified and counted; nauplii and copepodites were counted but not identified.

To continue monitoring the abundance of Mysis relicta, the opossum shrimp in Flathead Lake, we sampled three mid-lake stations in mid-June. These sites were 1.6 km west of Yellow Bay, 1.6 km west of Yenne Point, and 3.2 km southwest of Bigfork. We made replicate vertical tows through the entire water column with a 1.0 meter diameter, 500 micron mesh Wisconsin plankton net. Samples were preserved in 4% formalin with sucrose. The entire sample was examined for adult and juvenile Mysis under a binocular stereoscope.

TAGGING STUDIES

On February 27, March 15, and March 24, 1984, adult kokanee were purse-seined in Skidoo Bay, after we located schools with a Sitex depth sounder. Three and four year old fish were marked with Floy tags and released. We tagged 4,525 fish, in four seine hauls, of which 30% were age III+ and IV+, and 70% were age II+. Each seine catch was tagged with a different color. These were fish expected to spawn the following fall. Recovery of tagged fish in the spring-summer fishery in the Lake, the fall fishery in the river, and from spawning areas in the river system and along the lakeshore enabled us to trace the dispersion routes of the aggregation of fish found in Skidoo Bay through the winter, and to determine their spawning destination.

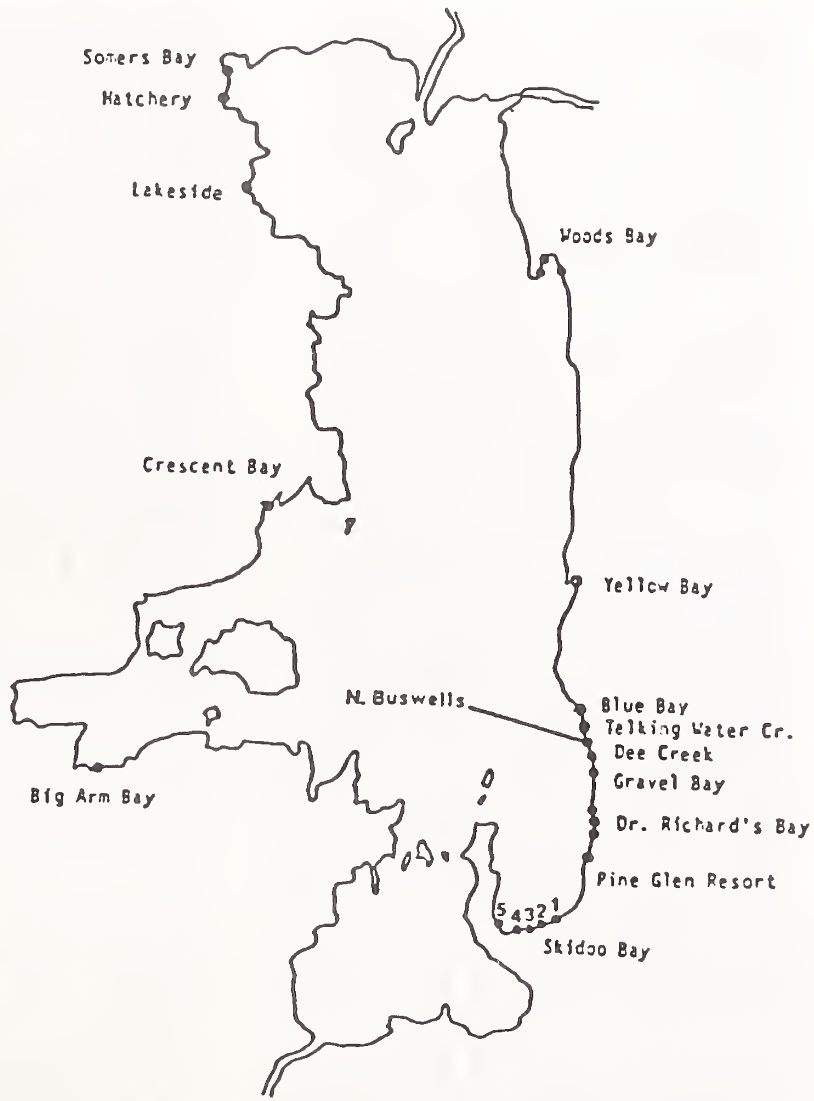
RESULTS AND DISCUSSION

SPAWNER SITE INVENTORY AND SPAWNER COUNTS

In 1984, Kokanee spawned at 19 sites along the shore of Flathead Lake in addition to adfluvial spawning in the Upper Flathead River, its tributaries, and the Swan River (Fig. 4). All but four of these lakeshore areas are on the eastshore, as has been observed in the previous 3 years (Decker-Hess and Graham, 1982; Decker-Hess and McMullin, 1983; Decker-Hess and Clancey, 1984). Spawning was observed for the first time in 4 years at two areas between Blue Bay and Gravel Bay, at Thurstons (Skidoo Bay V), and in Big Arm Bay. The consistent lack of west shore sites is not presently explained, particularly in light of abundant spawners at numerous west shore sites from historical records (Stefanich, 1953; Decker-Hess and Graham, 1982; Decker-Hess and McMullin, 1983). Kokanee did not spawn in Yellow Bay, Lakeside Bay (Stoner Creek), or at the Dr. Richards Site in the fall of 1984. As in previous years, we observed no spawning in Polson Bay. Spawning in Swan River occurred on the north shore of Bigfork Bay, in the Bigfork Powerhouse forebay, and below the diversion dam.

The total number of lakeshore redds in 1984 was 1,134, the highest count in four years (Fig. 4). The largest number of redds (29% of the total) was observed at Gravel Bay. Other principle areas included Skidoo Bay, Woods Bay, and Dr. Richards Bay. Redd counts at Talking Water Creek and Dee Creek were substantially higher than in the previous three years. Redd counts reported during this study have been peak numbers, i.e. the highest number observed during weekly observations from 15 October to 20 December. They may underestimate spawning because: 1) wave action during frequent storms obliterates redds in the shallow littoral zone, so that redds do not persist between counts or are never counted at all; 2) our ability to detect redds in water deeper than 6 m is limited by poor visibility; 3) the efficiency of observing and counting redds from the surface, or by diving must be less than 100%.

The number of adult kokanee comprising the 1984 spawning run can be estimated, but a direct count is subject to innaccuracy. The residence time of fish over spawning sites must be known to validate weekly observations. Estimates of residence time for kokanee in the Flathead system vary between seven and thirty days (Decker-Hess and Clancey, 1984; Fraley and Graham, 1982). Pfiefer (1978) observed a mean residence time of 14 days in Lake Stevens, Washington, but noted considerable variation, between 5 and 21 days, dependent on fish maturity. If we assume that successive fish counts in Flathead Lake spawning areas, made more than 2



AREA	REDD COUNT 1981	1982	1983	1984
WOODS BAY	57	188	76	176
YELLOW BAY	152	197	79	0
BLUE BAY	45	55	45	30
TALKING WATER CREEK	12	4	33	45
NORTH BUSWELLS	0	0	15	115
DEE CREEK	0	16	0	0
GRAVEL BAY	37	238	187	326
DR. RICHARDS BAY	181	87	52	101
PINE GLEN	45*	85	0	90
SKIDOO BAY	103	126	200	169
BIG ARM BAY	0	0	0	13
CRESCENT BAY	5	31	19	13
LAKESIDE BOAT RAMP	0	2	2	0
HATCHERY	15*	10*	12*	50*
SOMERS BAY	0	0	28	1*
TOTAL	652	1,039	743	1,134

* Estimated Counts

Figure 4. Flathead Lake spawning sites, and redd counts at these sites from 1981 to 1984.

weeks apart represent different fish, a total of 1,165 spawners were counted in the fall of 1984. The accuracy of these counts is also limited by our inability to make instantaneous counts, at regular intervals, over 100 miles of shoreline. We have not observed kokanee, having died after spawning, to wash up on the shore of Flathead Lake. In the Upper Flathead River system, an average of 2.4 kokanee are associated with each redd constructed (Fraley and Graham 1982). Using this expansion we can estimate the lakeshore escapement to be 2,673 fish. This sum represents 2.3% of the total spawning run in the Flathead system, in 1984.

Timing of the 1984 run resembled those in the preceding three years, with initial observations on October 24 and the last observations on December 20 (Figure 5). However, in addition to an early peak of spawning around November 6, a later peak occurred on eastshore sites at the end of November. New redds were built at Gravel Bay, the principle spawning area, as late as December 15. The Swan River run began earlier about September 14, and ended about December 20, with peaks in escapement observed October 10, November 5, and November 26. With some variation in the occurrence of peak counts, the timing of lakeshore spawning is consistent over the four years of this study, and with earlier observation in the early 1950's (Stefanich, 1954). Onset of spawning has been observed to coincide with water temperatures from 5-10.5^{o}C (Decker-Hess and Clancey, 1984; Scott and Crossman, 1973).

AGE, SEX AND LENGTH OF SPAWNERS

Gill net samples from lakeshore spawning sites yielded the age, sex, and length information presented in Table 1. The mean length of spawners, 374 mm for males and 356 mm for females, has declined since 1983. The percentage of age III+ fish comprising the spawning run was 77% and 79% for males and females respectively. Since 1980, the percentage of age III+ and II+ fish has been increasing, and the percentage of IV+ declining. This partially explains the recent decreasing average size of spawners. Older fish are more vulnerable to fishing, but we have no evidence that fishing pressure has increased over the last four years. The size of spawners is affected both by age composition, density dependent interactions with adjacent year classes, and relative abundance of food, especially in the first two years of life (Hanzel, 1984). Year class strength, and thus size of fish, has also been affected by the operation of Kerr and Hungry Horse Dams. Fraley and Decker-Hess (1985, in press) have shown that the size of III+ kokanee is related to the difference in gauge height between the spawning and incubation period in the Flathead River, and the length of time that Flathead Lake was held below 2,885 feet during winter drawdown. Age II+ fish (both sexes combined) comprised 18% of the 1984 spawners, age IV+ fish were 4% of the total. Of kokanee sampled by gill nets in lakeshore spawning areas, between 51% and 89% were males, the combined overall sex composition being

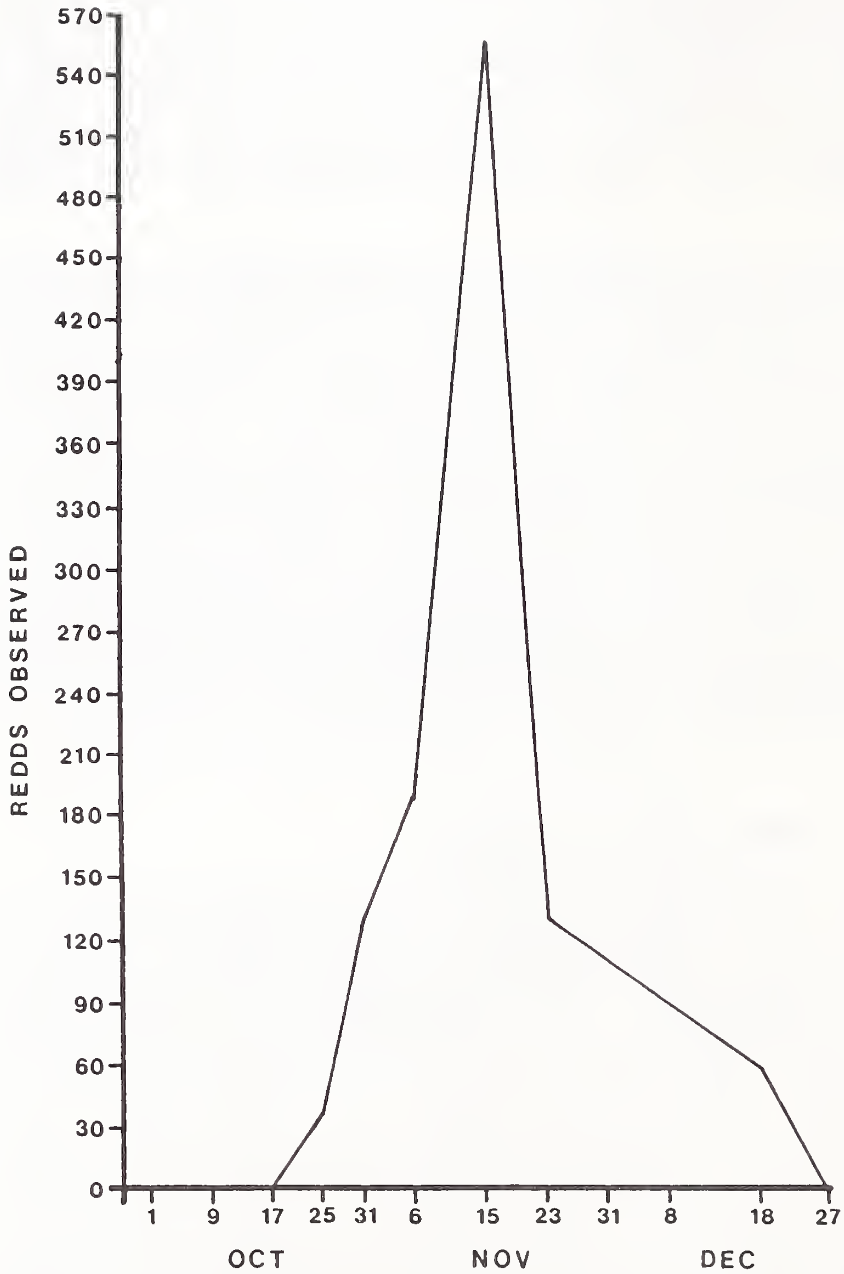


Figure 5. Timing of the 1984 Flathead Lakeshore spawning run, represented by weekly counts of new redds from October 15 to December 31.

Table 1. Sex ratio, age composition, and mean length of kokanee spawners (at lakeshore spawning areas) in 1984.

Area	Sex	Percent Comp	Age Percent III+	Mean length (mm)
Woods Bay West	M	68	86	377
	F	32	100	362
Woods Bay East	M	70	89	370
	F	30	100	359
Hatchery Egg Take	M	51	18	348
	F	49	34	335
Dr. Richards	M	71	93	374
	F	29	92	363
Thurston's (Skidoo)	M	79	85	377
	F	21	86	354
Pineglen	M	59	88	377
	F	41	89	356
Gravel Bay	M	85	88	377
	F	15	95	372
North Buswell's	M	89	74	380
	F	11	86	375
Blue Bay	M	77	85	378
	F	23	100	363
Lake Overall	M	73	77	374
	F	27	79	356
River Overall	M	49	81	354
	F	51	88	337

73% male. These figures are strongly influenced, however, by the fact that males, with strongly developed kypes and jaw teeth, are more vulnerable to gill nets. The sex composition of spawners also varies through the spawning period, with males predominant early in the season.

The mean size of spawning males at nine lakeshore areas, varied between 348 mm (Somers hatchery) to 380 mm (Buswells); females ranged from 335 mm (Somers hatchery) to 375 mm (Buswells). Spawners at the hatchery were smaller because they were predominantly age II+ fish. The mean size of both sexes exceeded that of river-spawning kokanee in 1984. Lakeshore spawning occurs later than in the river.

SPAWNING SITE CHARACTERIZATION

Elevation

Kokanee constructed redds along the shores of Flathead Lake between the elevations of 2,889 feet (880.6 m) and 2,862 feet (872.3 m). During spawning the lake was drawn down from 2,891.2 ft (881.2 m) to 2,887.10 ft (880.0 m). The depth of redds varied from 1.4 feet to 25.4 feet (0.43-7.74 m), and 60% of the redds were in 7 feet of water or less. Expressed in terms of elevation, 680 (62%) of the redds we observed were above minimum pool (2,883 ft., 878.7 m) and 408 (38%) were below minimum pool (Figure 6). These findings substantiate data on redd elevations gathered since 1981 (Decker-Hess and Graham, 1982; Decker-Hess and McMullin, 1983; Decker-Hess and Clancey, 1984). They also agree with studies on kokanee in Coeur d'Alene Lake and Priest Lake in Idaho (Hassemer and Rieman, 1979 and 1980) and Banks Lake in Washington (Stober et al., 1979). However, Hassemer and Rieman (1980) reported extensive spawning to depths of 60 feet on artificial, large substrate road fill in Coeur d'Alene Lake. In Flathead Lake, the extent of spawning below minimum pool is a strong influence on the success of recruitment from lakeshore redds. Overwinter mortality is very high in redds above minimum pool, that are exposed during drawdown.

As in previous years, spawning at Gravel Bay and Blue Bay was almost entirely below minimum pool. However, significant numbers of redds were below minimum pool at Woods Bay West, Pineglen and Dr. Richards Bay (Table 2). Spawning at other areas occurred entirely at elevations above minimum pool. Our estimates of spawning below minimum pool are probably low, due to the difficulties of locating and counting redds in deep water. Redd counts above and below minimum pool, at principal shoreline areas, for 1981 to 1983 are tabulated in Appendix A.

Substrate Size Composition

The size composition of substrate is regarded as one of the principle criteria by which salmonids select spawning sites. Apart from providing visual cues to fish, substrate size also determines the porosity of gravels, and thus the rate of flow of water through the substrate. Flow rate, in turn, determines oxygen availability, flushing of organic waste, and thus influences egg and alevin survival. The photographic method we used to assess substrate size composition is fast and simple but it has some limitations. Photographs depict only the surface of the substrate which frequently is composed of larger particles. Fines may be concealed by this armoring layer. Thus a picture of undisturbed substrate may not represent the overall composition of spawning gravel. During redd construction the fish mixes the substrate, so that a photograph taken after spawning may not resemble the undisturbed site. We analyzed photographs of sub-

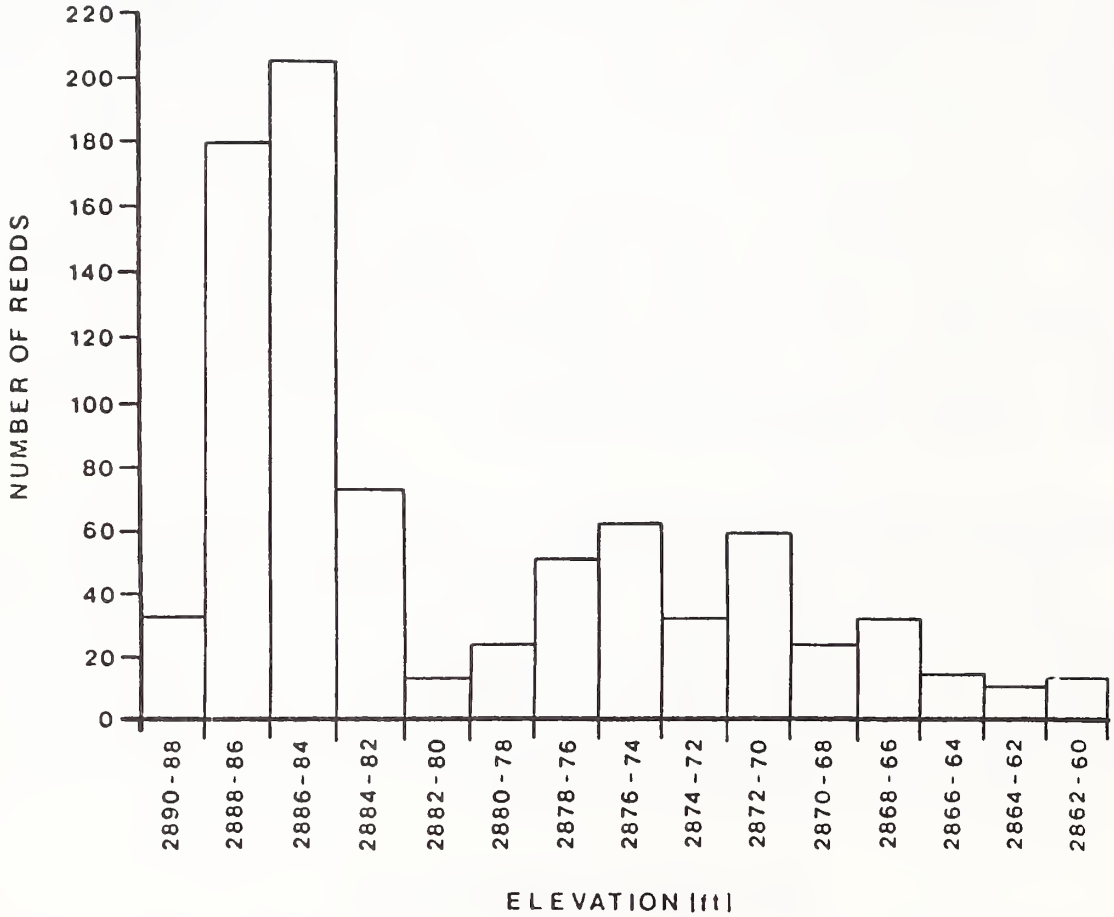


Figure 6. The distribution of the elevation of shoreline redds, on Flathead Lake, in 1984.

Table 2. Final SCUBA counts of kokanee redds by area and number above and below minimum pool in shoreline areas of Flathead Lake, 1984.

Location	Number above Minimum Pool (percent)	Number below Minimum Pool (percent)
Woods Bay		
East	65 (100)	0
West	79 (71)	32 (29)
Blue Bay	0	30 (100)
Talking Water Creek	45 (100)	0
Miscellaneous Eastshore Sites	46 (100)	0
Gravel Bay	16 (5)	310 (95)
Pine Glen	78 (87)	12 (13)
Skidoo Bay		
II	102 (100)	0
III	2 (100)	0
IV	22 (100)	0
V	43 (100)	0
Crescent Bay	18 (100)	0
North Buswells	66 (98)	7 (2)
Somers Bay	1 (100)	0
Big Arm Bay	13 (100)	0
Dr. Richards Bay		
G. Boat launch	44 (72)	17 (28)
North	24 (100)	0
South	16 (100)	0
Total	679 (62)	408 (38)

strate taken before and after excavation, and compared the resulting estimates of mean particle size, fredle index, and percent fines (<6.4 mm) with those from conventional sieve analysis (Appendix Table A-1). In comparing photo with sieve analysis, mean particle size was 3.3 mm smaller, Fredle index was 2-3 points lower, and fines were higher by 3.7%. In photos taken after the site was disturbed to mimic redd-building activity, mean particle size was an average of 1-2 mm larger, fredle index was 0.8 points higher, and percent fines 3% lower than sieved samples. Six samples do not achieve a statistically significant comparison, but photo analysis apparently yields accurate characterization of particle size composition. Comparison of the two methods across all particle size classes is tabulated in Appendix Table A-1.

Our analysis indicates that substrate quality is not limiting survival at the principle shoreline spawning areas on Flathead Lake. Fredle numbers from photographs of redds ranged from 3.5 to 29.4; the mean of 93 observations was 12.0. Seventy-one percent of the values were within the range of 5 to 15 (Figure 7). Lotspeich and Everest (1980) reported that fredle numbers below 4 characterize poor salmonid spawning habitat, 5-9 indicate good quality, and above 9 characterize high quality habitat in streams. The effects of substrate size on spawning habitat quality are similar in streams and lakeshores.

The variability of the substrate in some areas makes strict interpretation of such analyses difficult without a vastly larger, more random sample. Subjectively, some spawning areas appear to have homogeneous substrate, i.e. consistent sized cobble and gravel, while others (e.g. Pineglen and Thurstons) are characterized by patches of gravel interspersed with large boulders and heavy cobble armoring. Kokanee are certain to select substrate that they can excavate for spawning and within that size range optimum substrate can be characterized by fredle index of 5-15.

Groundwater Hydrology

We measured groundwater flux (discharge/area) at five spawning areas in 1982, eight spawning areas in 1983, and in 93 redds, at 9 areas, in 1984. The resulting data set adequately describes the spatial and temporal variation in flux, at spawning areas. In general, discharge is highest near the lake/beach interface, and decreases as the distance from shore increases (Figure 8). Very few measurements were made at sites above 2,887 feet due to the interference of wave action with seepage meter operation. All values greater than 1.0 cm/hour were recorded at sites above 2,886 feet, except one at Pineglen. Values from sites below 2,886 feet varied less, with 70% of values recorded over redd sites in 1984 falling between 0.05 and 0.40 cm/hour (Figures 9 and 10). This range of apparent velocity is typical of redd sites at elevations from 2,886 feet down to 2,870 feet. A lower range, from 0.01 to 0.15 cm/h, is typical of deep sites below 2,870 feet. Decreasing

apparent velocity, as the distance from shore increases, is related to the longer groundwater flow path and the lower hydraulic conductivity of the deeper lakebed. The low variability in discharge rate measured in redd sites at various spawning areas allows us to define the 0.10-0.40 cm/h range as optimal for kokanee spawning along the Flathead Lake shoreline.

Kokanee spawning areas on the shore of Flathead Lake are all in zones of stream or groundwater discharge. The latter are typically in areas of unconsolidated glacial till through which groundwater, recharged by precipitation over the watershed, flows toward the lake. Near the surface of the water table the direction of movement is roughly parallel to the landform slope (Fig. 8), so groundwater flux is highest near the lake beach interface. The hydraulic slope of the water table, the hydraulic conductivity, and the cross-sectional area of the aquifer are the principle variables controlling groundwater discharge (Woessner, Brick, and Moore, 1985). Groundwater seeps are frequently observed below sharp gradients in the beach profile.

Though tributary spawning is the more common behavior in kokanee, there are numerous references to lakeshore spawning for kokanee and sockeye (Hart, 1973; Foerster, 1968; Stefanich, 1953). These references frequently mention that shoreline spawning is associated with tributary discharge and groundwater seepage, but seepage in redds has not been quantified. Homing to specific lakeshore sites in Flathead Lake has not been proven, but there is considerable circumstantial evidence that kokanee have spawned in the same groundwater discharge areas over successive generations. Marked fry released at the Somers hatchery returned there to spawn (Hanzel, pers comm.). Groundwater seeps might provide chemical cues for salmon to home to these sites, as would creek discharge flowing over and through beach substrate.

In some spawning areas, the groundwater table remains elevated, as the lake is drawn down in winter. At Orange House and Thurstons, in Skidoo Bay, groundwater seeps flow over the beach surface. At Woods Bay and Gravel Bay, by contrast, the groundwater table falls at the same rate as the lake level during drawdown. These differences in groundwater regime can be related to the hydraulic conductivity of the beach aquifer. In high conductivity substrate the groundwater table falls rapidly, whereas in low conductivity zones the fall is delayed to varying extents, depending on the rate of aquifer recharge. Conceptual models of lakeshore aquifers often assume that hydraulic conductivity does not vary vertically or horizontally. On Flathead Lake, by contrast, conductivity, groundwater flux, and the groundwater table elevation all vary spatially, even at small scales. The effects of this variable groundwater regime on kokanee egg survival are discussed later in this report.

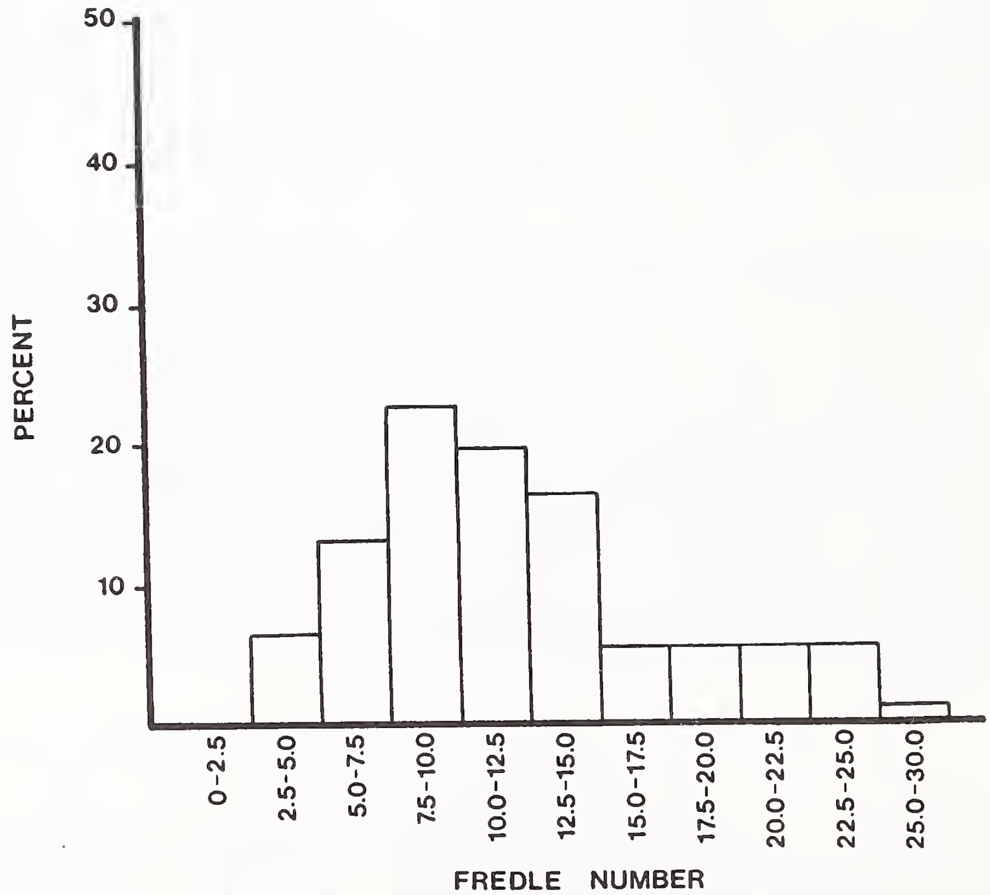


Figure 7. The distribution of the fredle index, calculated from particle size distribution, in 93 shoreline redds in Flathead Lake.

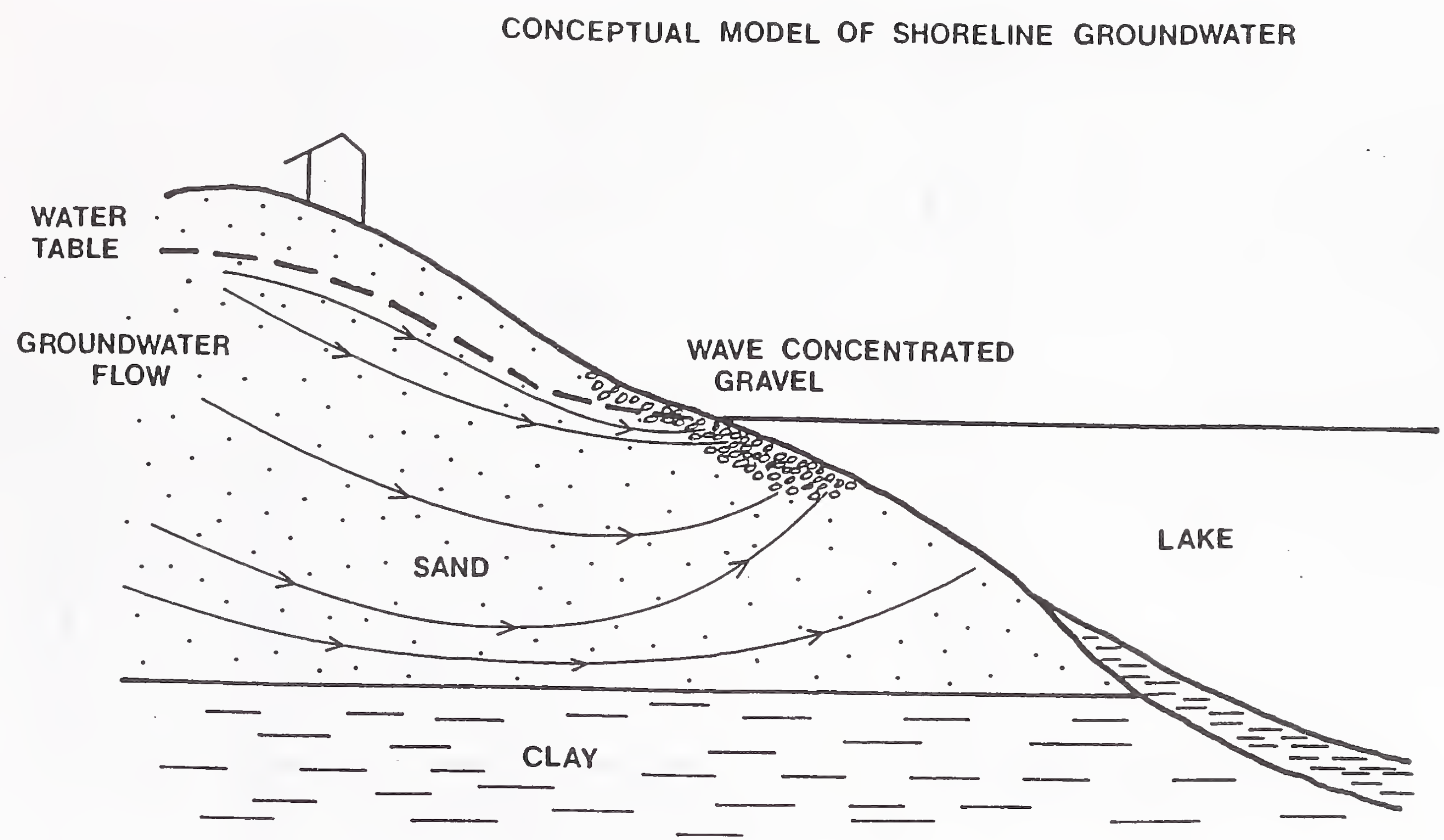


Figure 8. Conceptual view of groundwater discharge into a lake basin, showing flow paths at different depths in the aquifer (from Woessner and Brick, 1985).

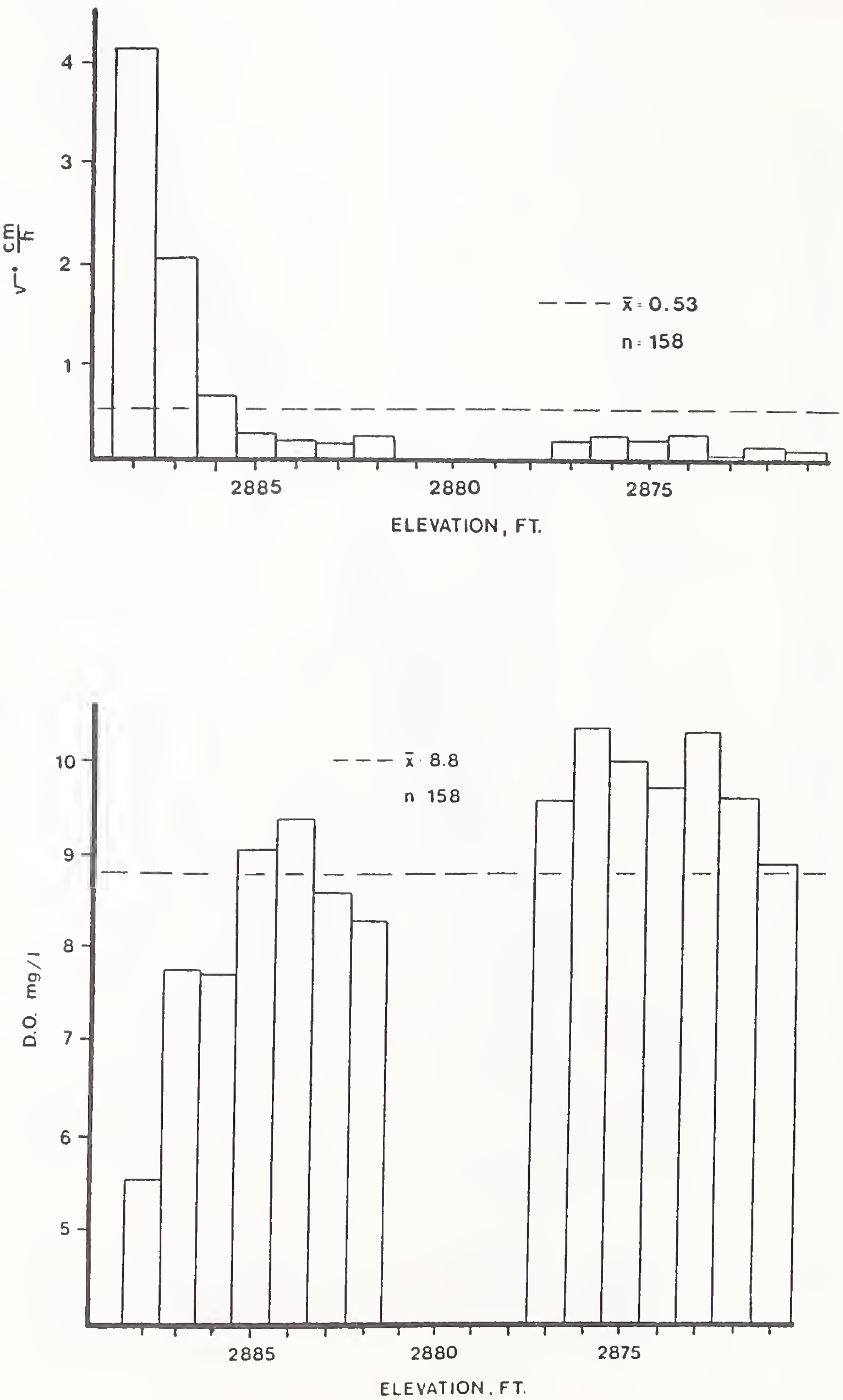


Figure 9. Mean apparent velocity (discharge/area) and dissolved oxygen values in redds on the shore of Flathead Lake. Values are collected for one foot increments of elevation from 2,870 to 2,888 feet.

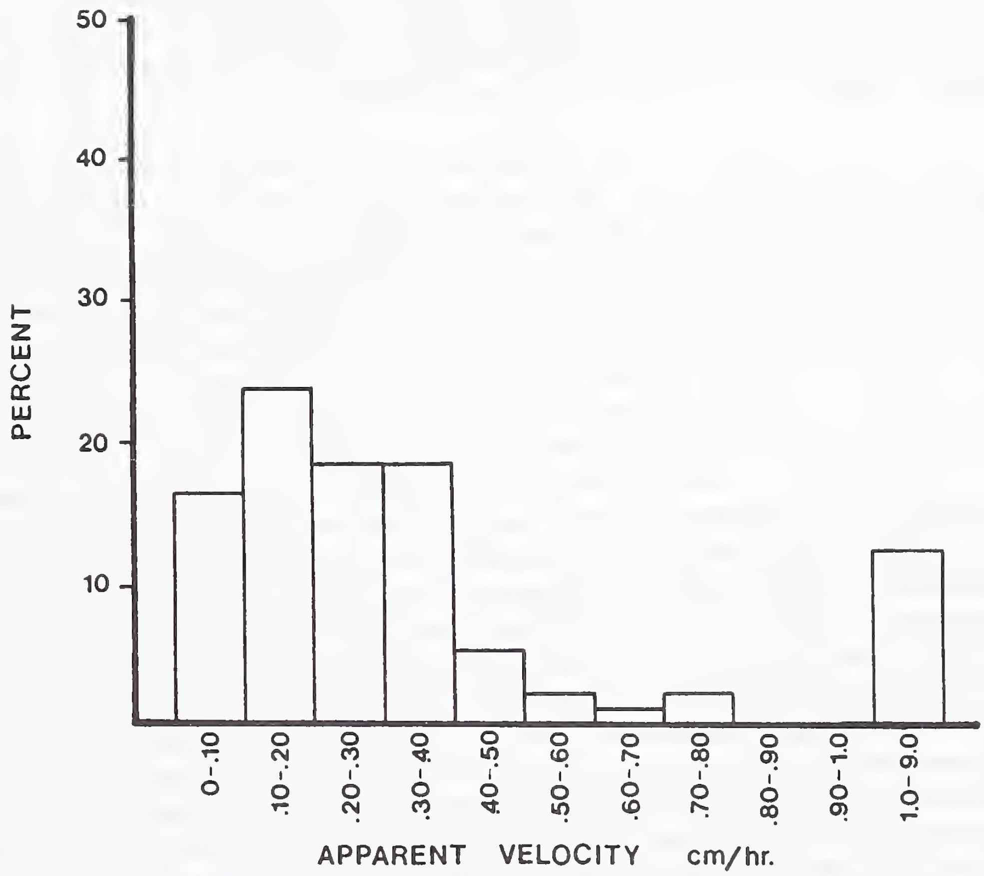


Figure 10. The distribution of groundwater discharge values (apparent velocity) in Flathead Lake shoreline redds.

Effects of Drawdown on Groundwater Discharge

As lake stage declines during drawdown, groundwater stage tends toward equilibrium with lake level. Near the lake/beach interface there are at least temporary increases in hydraulic slope as the lake level drops. If we view the lakebed aquifer as wedge shaped, decline in lake stage involves a decrease in the cross sectional area of the aquifer in the discharge zone. These two factors would, according to Darcy's law, cause increased discharge. We have not observed consistent agreement with this prediction in Flathead Lake spawning areas, probably because of seasonal changes in aquifer recharge rate nd the variability of hydraulic conductivity in the beach aquifer.

The three types of groundwater response to lake drawdown observed in Flathead Lake (Decker-Hess and Clancey, 1984; Woessner and Brick, 1984) are due to the variability of hydraulic conductivity and recharge rate, and the resulting variability in tendency of the groundwater table to equilibrate with lakestage. In sites where the groundwater table declines at the same rate as lake stage (Type I), high hydraulic conductivity and low winter recharge allow the groundwater table to equilibrate rapidly with lake stage. At Type III sites the groundwater table remains high during drawdown. High recharge rate and low hydraulic conductivity prevent the groundwater table from equilibrating with lake stage. Hydraulic slopes in the beach area remain high, and active groundwater seeps persist during drawdown. Spawning sites at Gallaghers and Thurstons (Skidoo Bay III,IV, & V), typify this groundwater regime. High recharge is associated with tributary streams in some type III sites, e.g. Dr. Richards North. Type II sites, where the groundwater table initially declines relatively slowly during drawdown, then levels off and remains constant as drawdown continues, can also be related to the conductivity of beach strata and recharge rates. Strata of low hydraulic conductivity in the lower beach area maintain a high groundwater stage after an initial period of rapid equilibration in more permeable strata at higher elevation. Recharge is consistently high in these shore areas, such as Orange House. Woessner and Brick (1985) constructed a finite difference numerical model of the Type II groundwater system at the Staples spawning area. They abstracted a 100 foot section of shoreline, assumed impermeable boundaries, and input values of hydraulic conductivity, hydraulic slope, aquifer thickness, and lake stage. The model closely predicted the changes in groundwater table elevation, associated with drawdown and refill of the lake observed in seven local groundwater wells.

The model has enabled us to estimate the length of time of exposure in redd sites at any beach elevation influenced by this Type II groundwater regime. We assumed that the groundwater table wets substrate for 15 cm above actual groundwater level by capillary action. Table 3 presents results of running the pre-

dictive model for the period 1961-1970, during which major declines in the lakeshore spawning run occurred.

The tolerance of eyed kokanee eggs to desiccation varies, dependent on groundwater availability and air temperature. Complete mortality occurred after periods of exposure ranging from 50 to 98 days (Decker-Hess and McMullin, 1983; Decker-Hess and Clancey, 1984) in natural redds and experimental egg plants. Air temperatures below -10^{O}C curtail egg survival dramatically. Green eggs are more susceptible to desiccation, freezing mortality, and oxygen stress, with 90% mortality occuring after 10 hours exposure (Fraley and Graham, 1982). Thus, early drawdown during the years 1961-2, 65-6, 66-7, and 69-70 probably resulted in high mortality in redds above 2,885 feet.

Though we have no spawner surveys from this period (1960-1970), it is likely that a larger proportion of Flathead Lake kokanee spawned in shallow water, given their spawning habits in other northwestern lakes. Drawdown could have affected a larger proportion of lakeshore-spawned eggs and caused high egg mortality.

Groundwater Chemistry

In general, there is no evidence that groundwater quality has deteriorated in spawning areas. Only one site, Table Bay, showed consistent evidence of domestic water use influencing groundwater quality. Bicarbonate, sulfate, nitrate, the three cations, and total dissolved solids were all substantially higher at Table Bay than background levels measured at other lakeshore sites. Bicarbonate, calcium, magnesium, and TDS were high enough to suspect domestic contamination. Typically, if these solutes increase 50, 15, 15, and 150 mg/l respectively, contamination from domestic water use is suspected (G. Phillips, pers. comm.). One sample from Orange House was high in sulfate (OH-219 on 2/22). Otherwise, successive samplings at wells did not show any marked variation in any constituent we measured.

Optimal Spawning Habitat

After examining the distribution of redd sites across the various increments of elevation, apparent velocity, dissolved oxygen, and substrate composition, we arbitrarily defined optimal spawning habitat by the range of these parameters into which 70-80% of the redds fall. The elevation of 95 redds was distributed bimodally, with 60% in the range from 2,882.5 to 2,887.5 feet. Another 26% were distributed deeper, between 2,867.5 and 2,877.5 feet (Figure 6). Dissolved oxygen in groundwater pumped from spawning substrate was between 8.0 and 11.0 mg/l in 73% of the redds and greater than 6.0 mg/l in 87% of redds. Groundwater flux, or apparent velocity, was between 0.05 and 0.40 cm/h in 70%

Table 3. Exposure time, at six beach elevations, due to lake drawdown, compared with that due to groundwater stage decline. Change in groundwater stage was modelled at the Staples area, in Skidoo Bay, on Flathead Lake. (data from Woessner & Brick 1985).

	Elev.	Days exposed from Lake	Dates	Days exposed from Groundwater	Dates
1960-61	84.75	0	--	0	--
	85.65	0	--	0	--
	86.80	0	--	0	--
	87.40	60	2/2-2/27, 3/9-4/13	0	--
1961-62	84.75	41	3/14-4/23	0	--
	85.65	55	3/04-4/28	55	2/27-4/28
	86.80	71	2/22-5/03	55	2/27-4/28
	87.40	86	2/17-5/03	66	2/12-5/08
1962-63	84.75	0	--	0	--
	85.65	0	--	0	--
	86.80	10	4/28-5/08	0	--
	87.40	77	3/14-5/23	5	5/03-5/08
1963-64	84.75	35	4/03-5/08	0	--
	85.65	40	4/03-5/13	40	4/03-5/13
	86.80	60	3/24-5/23	40	4/03-5/13
	87.40	70	3/14-5/23	55	3/29-5/23
1964-65	84.75	0	--	0	--
	85.65	10	4/13-4/23	10	4/13-4/23
	86.80	25	4/08-5/03	5	4/18-4/23
	87.40	35	4/03-5/08	25	4/08-5/03
1965-66	84.75	30	3/24-4/23	0	--
	85.65	55	3/19-5/13	55	3/19-5/13
	86.80	65	3/09-5/18	55	3/19-5/13
	87.40	75	3/04-5/18	65	3/14-5/18
1966-67	84.75	15	4/08-4/23	0	--
	85.65	50	3/29-5/18	50	3/29-5/18
	86.80	80	3/09-5/28	50	3/29-5/18
	87.40	85	3/04-5/23	75	3/14-5/28
1967-68	84.75	15	4/28-5/13	0	--
	85.65	30	4/18-5/18	30	4/18-5/18
	86.80	65	3/24-5/28	30	4/18-5/18
	87.40	>70	3/29->5/28	60	3/29-5/28
1968-69	84.75	0	--	0	--
	85.65	10	4/03-4/13	10	4/03-4/13
	86.80	40	3/14-4/23	10	4/03-4/13
	87.40	66	2/22-4/28	30	3/24-4/23
1969-70	84.75	45	3/29-5/13	0	--
	85.65	55	3/29-5/13	55	3/19-5/13
	86.80	91	2/17-5/18	55	3/19-5/13
	87.40	106	2/07-5/23	75	3/04-5/18

of redds. Substrate composition, as expressed by the fredle index, was between 5 and 15 in 71% of the redds.

Comparison of data gathered in redd and non-redd sites showed little difference in the distribution of elevation, apparent velocity, and dissolved oxygen (Figure 11), or particle size distribution (Table 4). Non-redd sites were mostly within the perimeter of spawning areas. At the nine shoreline areas where we analyzed the substrate, we compared redd sites with adjacent substrate where no redds were constructed. Based on limited sampling, usually less than 10 samples per area, fredle numbers did not vary greatly between redd and non-redd samples at any given spawning area. However, at Pineglen and Dr. Richards Bay, the mean Fredle index at non-redd sites was more than 5 points higher than redd sites. At these two areas kokanee appear to be selecting smaller size substrate, i.e. avoiding large cobble/small boulders, as the mean size at non-redd sites was considerably larger than in redd sites. Given the low numbers of lakeshore spawners, it is not surprising that areas of suitable spawning habitat are not fully utilized. Further study is needed to ascertain whether changes in beach substrate, due to erosion and deposition, may explain why lakeshore spawning kokanee no longer use some historic spawning areas.

Groundwater dissolved oxygen and apparent velocity data were stratified into five foot elevation intervals in an attempt to characterize the vertical variation of these parameters. The distribution of dissolved oxygen is skewed toward values above 6.0 mg/l in all depth zones (Appendix Table A-5). With the exception of one sample at Orange House and one at Dr. Richards, all D.O. values below 6.0 ppm were from Thurstons and Big Arm, in the 2,885-90 foot interval. In previous studies, dissolved-oxygen levels have been below 6.5 mg/l during spawning at deep sites in Yellow and Gravel Bay (Decker-Hess and Clancey, 1984). No samples below 2,875 feet from Blue and Gravel Bay were below 6.0 mg/l. This may explain why kokanee spawn at deep sites in these areas.

Groundwater discharge values were widely distributed above 2,880 feet, with 17 samples above 0.50 cm/h. All values above 1.0 cm/h were from this zone but their accuracy is affected by the influence of wave action on seepage meter measurements. We could expect groundwater flux to be an order of magnitude higher at high elevation than 10 to 20 feet downslope due to the flow path of groundwater and higher hydraulic conductivity of sediments high on the shore (Woessner and Brick, 1985). The majority of flux measurements below 2,875 feet were 0.20 cm/h or less. However, the spatial heterogeneity of discharge, i.e. of aquifer structure, creates a wide range of flux in all the elevation intervals.

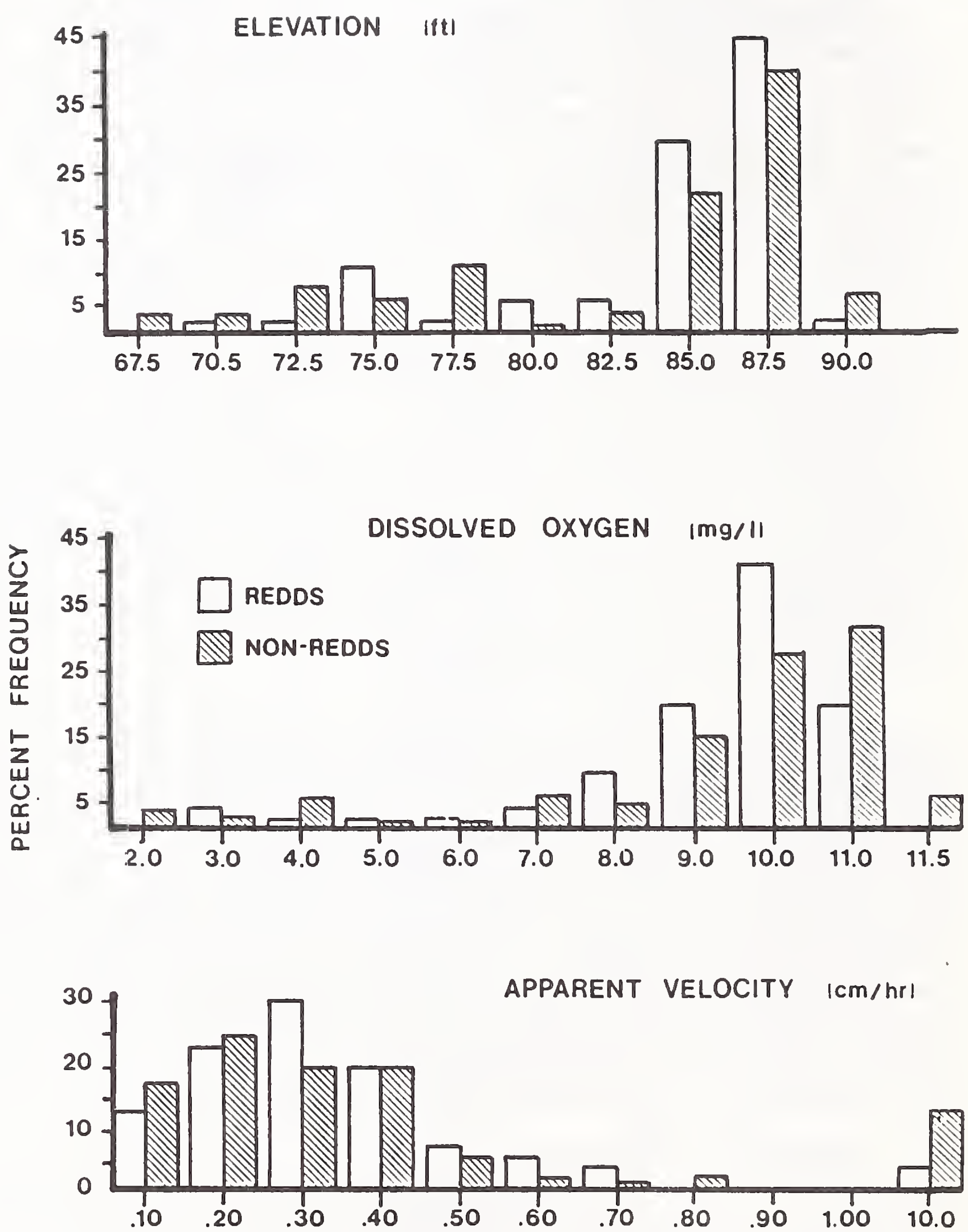


Figure 11. Comparison of the distribution of elevation, dissolved oxygen, and apparent velocity in redd (clear bars) and non-redd (shaded) sites on Flathead Lake.

Table 4. Mean fredle index at redd and non-redd sites in principle Flathead Lake spawning areas.

Area	$\bar{x}$ Fredle Number	Sample Size
Pine Glen		
Redd	14.6	13
Non-redd	19.7	5
Staples (Skidoo I)		
Redd	7.2	9
Non-redd	4.9	7
Woods Bay West		
Redd	10.2	8
Non-redd	14.8	7
Woods Bay East		
Redd	12.2	8
Non-redd	15.3	6
Blue Bay		
Redd	7.7	10
Non-redd	6.4	6
Dr. Richards		
Redd	16.6	10
Non-redd	23.8	6
Gravel Bay		
Redd	14.3	21
Non-redd	14.7	8
Thurston's (Skidoo V)		
Redd	7.4	10
Non-redd	9.8	7
Big Arm		
Redd	15.8	4
Non-redd	15.4	2

EGG AND ALEVIN SURVIVAL

Natural Redd Sampling

We excavated 35 redds at 8 spawning areas on the shores of Flathead Lake from January 10 to April 4, 1985, to estimate egg/embryo survival. Results of natural redd sampling are tabulated in Appendix Table A-6. The following discussion summarizes the results by area.

At Woods Bay East, five redds were sampled between January 30 and March 13, 1985. Survival to the eyed-egg stage varied from 1% after 34 days exposure to 50% after 42 days exposure. There was no evidence of successful hatching. All 65 redds counted at Woods East in 1984 were above minimum pool, as in 1982 and 1983.

In five redds sampled at Woods Bay West on March 13, all eggs were desiccated and/or frozen. We found 50 early sac-fry, of which 3 (4%) were alive at time of sampling. Recruitment from the Woods West area, thus, was very low from the 80 redds above minimum pool. Eggs deposited in the 30 redds below minimum pool were not sampled but would be expected to have a higher chance of survival.

At Dr. Richards North in 1984 we found very few eggs and no survival in redds near the mouth of Station Creek. Though survival was similarly low at this area in 1982, egg survival was at least prolonged by groundwater discharge in 1983 and 1984 (Decker-Hess and McMullin, 1983; Decker-Hess and Clancey, 1984). Another factor contributing to egg/embryo mortality at Dr. Richards Bay was substrate transport associated with exposure to wind and wave action. The only potential recruitment from this area in 1985 would have been from the 17 redds below minimum pool, at Dr. Richards North.

We sampled six redds above minimum pool at Orange House (Skidoo Bay II) between January 29 and March 13, 1985. Early sampling, after 16-35 days exposure, showed 50-100% egg and alevin survival. After longer exposure, 63-76 days, egg mortality had increased, but 80-100% of the sac-fry observed were still alive. The persistence of high egg/embryo survival at Orange House, in spite of drawdown exposure, is related to the groundwater regime in the area.

At Pineglen we sampled nine redds above minimum pool between January 30 and March 13, 1985. In redds at 2,886 feet after exposure times exceeding 25 days, there was very low egg survival (0-4%). At redds between 2884 and 2885 feet there was successful hatching and high alevin survival after 22 days of exposure. In spring of 1985, we observed schools of fry (2-500) swimming in shallow pools at the lake margin, indicating successful emergence. The groundwater regime at Pineglen is similar to Orange House

(Decker-Hess and Clancey, 1984). Variable survival is related to small-scale spatial variation in groundwater discharge, and the depth of the groundwater table in beach substrate.

We sampled five redds at Thurstons on January 28, and March 7, 1985. Egg survival varied between 0 and 93%. Live alevins were found in three redds as early as January 29 and on March 7. Impermeable strata in the beach substrate allow high volume groundwater seeps to persist at Thurstons all winter and spring. We observed hundreds of sac-fry in early March swimming down these seeps to the lake, a distance of 100 feet. The groundwater regime strongly enhances the over-winter survival of eggs and alevins and facilitates emergence.

Random excavation of redds to measure egg/embryo survival in exposed redds has contributed valuable information on reproductive success and the effects of lake drawdown. But the limitations of this type of sampling should be understood. Estimates of survival reflect the ratio of live and dead organisms found in the gravel. Previous loss of eggs due to egg retention, fertilization inefficiency, failure to bury eggs during spawning, egg predation by fish and invertebrates, dislocation of eggs during substrate transport, and decomposition of dead eggs would certainly bias the results from late winter/spring redd excavation. Our studies have not quantified these contributing factors. The results presented above indicate that survival varies greatly, temporally and spatially, at any given spawning area. We cannot achieve statistically significant measures of egg/embryo survival or of its variability without destructively sampling a large percentage of redds constructed on the lakeshore. Monitoring bags of fertilized eggs planted at a variety of sites and subjected to varying exposure conditions, is a better method to assess the reproductive success of kokanee in Flathead Lake.

Artificial Egg Bag Plants

Fertilized green kokanee eggs from the Somers hatchery were enclosed in lots of fifty in fiberglass mesh bags and buried at 2,884, 2,886, and 2,888 feet at Dr. Richards Bay (mouth of Station Creek) and Table Bay on November 20. Neither of these sites had been planted in previous years. Kokanee have spawned at the Dr. Richards site each of the past four seasons, but not recently at Table Bay. Each site was sampled twice. On December 20, at Table Bay, egg survival was 0% at 2,888 feet (exposed since 12/9), 98% at 2,886 feet, and 90% at 2,884 feet (Table 5). On April 11, eyed egg survival was 29% at 2888, and 0% in the two deeper lines. Ice cover on the bay precluded intermediate sampling of the two deeper lines. At Dr. Richards on December 20, the two shallow plants had been washed out, but egg survival was 50% at 2,884 feet. By January 22, egg survival was 0% at 2,884 feet. These results corroborate those from egg plants in previous years at other sites. Egg survival in exposed redds depends on moisture in the

substrate. Eyed-eggs are able to withstand desiccation and freezing in moist gravel, if ambient temperatures remain above -10°C. In moist gravel, hatched alevins do not survive more than 10 days, and cannot emerge unless the redd is below the groundwater table (Decker-Hess and McMullin, 1983; Fraley and Graham, 1982). Snow cover may insulate exposed redds from extreme air temperatures, and prolong egg survival. Short-term egg survival at deep sites not exposed by drawdown is high, but long-term survival through the eyed stage is frequently compromised by low dissolved oxygen in interstitial water (Decker-Hess and McMullin, 1983). Low groundwater flux and ice cover may decrease dissolved oxygen in lakebed substrate. The displacement of egg bags from the shallow lines at Dr. Richards points up another hazard for eggs deposited in loose gravel on exposed shorelines within the wave zone. The problem is accentuated by drawdown as the entire varial zone is subjected to wave action and thus substrate movement.

Emergence Monitoring

Survival to emergence was very low at Blue Bay, as ten traps caught only one fry over a 12 week (March 27-June 26) period (Table 6). At Gravel Bay, 31 traps caught 629 fry over a similar interval (April 12 - July 3). In 1985, emergence began the third week of April and peaked about the middle of June, slightly later than 1983 and a week earlier than 1984. (Figure 12). Ice cover on the lake postponed efforts to place emergence traps before April 1, and so earlier emergence at Gravel Bay may have been missed. The spawning area and emergent fry counts were stratified by 5 foot intervals of elevations from 2,885 to 2,860 feet. Traps were placed in each zone in proportion to the number of redds observed.

Total emergence at Gravel Bay was estimated at 67,039 fry, of which 84% emerged from redds between 2,870 and 2,880 feet. Of the estimated total egg deposition of 326,560, 65% was in redds within that zone. Overall survival to emergence was 20.5%, though it varied between 0.2% in the deepest zone, to 27% in the 2,871 - 2,875 foot zone (Table 7). In 1983 and 1984 survival to emergence was estimated to be 28% (Decker-Hess and Clancey, 1984; Decker-Hess and McMullin, 1983). Lindsay and Lewis (1975) in a five year study of kokanee in Odell Lake, Oregon, estimated that survival to emergence ranged from 29% to 56%. Their estimate was derived from hydraulic sampling of pre-emergent fry in a high density spawning area. A study of kokanee on Banks Lake, Washington (Stober et al. 1979) which utilized emergence traps, estimated 3 to 24% survival, depending on different assumed values for trap efficiency and residence time. Various studies of sockeye salmon (Foerster, 1968; McNeil, 1968; Mead and Woodall, 1968) have estimated survival to emergence at 7% to 19%. Varying values have been reported in Flathead River tributaries. Fraley and McMullin (1983) estimated survival to emergence at 50-75% in McDonald Creek in 1983, 22% in 1982 (Fraley and Graham, 1982), 4.5% in Whitefish

Table 5. Survival of eggs planted at three elevations at Table Bay and Dr. Richards Bay.

Site and sample date	Line	Stage of development	Percent Survival A/B	Comments
Table Bay 12/20/84	1A/B		0/0	Frozen
	2A/B		98/98	
	3A/B		83/98	
04/11/85	1A/B	Eyed	36/22	
	2A/B		0/0	
	3A/B		0/0	
04/25/85	3A/B	Eyed	0/0	
Dr. Richards 12/20	1		0	Washed out
	2		0	Washed out
	3A/B		52/48	
01/22	3		0	
Control 01/22			94	

Elevation of line 1 = 2,888 feet
2 = 2,886 feet
3 = 2,884 feet

Table 6. Emergence trap catch in Gravel Bay and Blue Bay in 1985.

	April			May			June					July	Total
	1-17	22	28	10	18	24	2	8	13	20	27	4	
Blue Bay No. traps=10	0	0	0	1	0	0	0	0	0	0			1
Gravel Bay No. traps=31	0	8	22	299	46	44	153	3	40	13	0	1	629

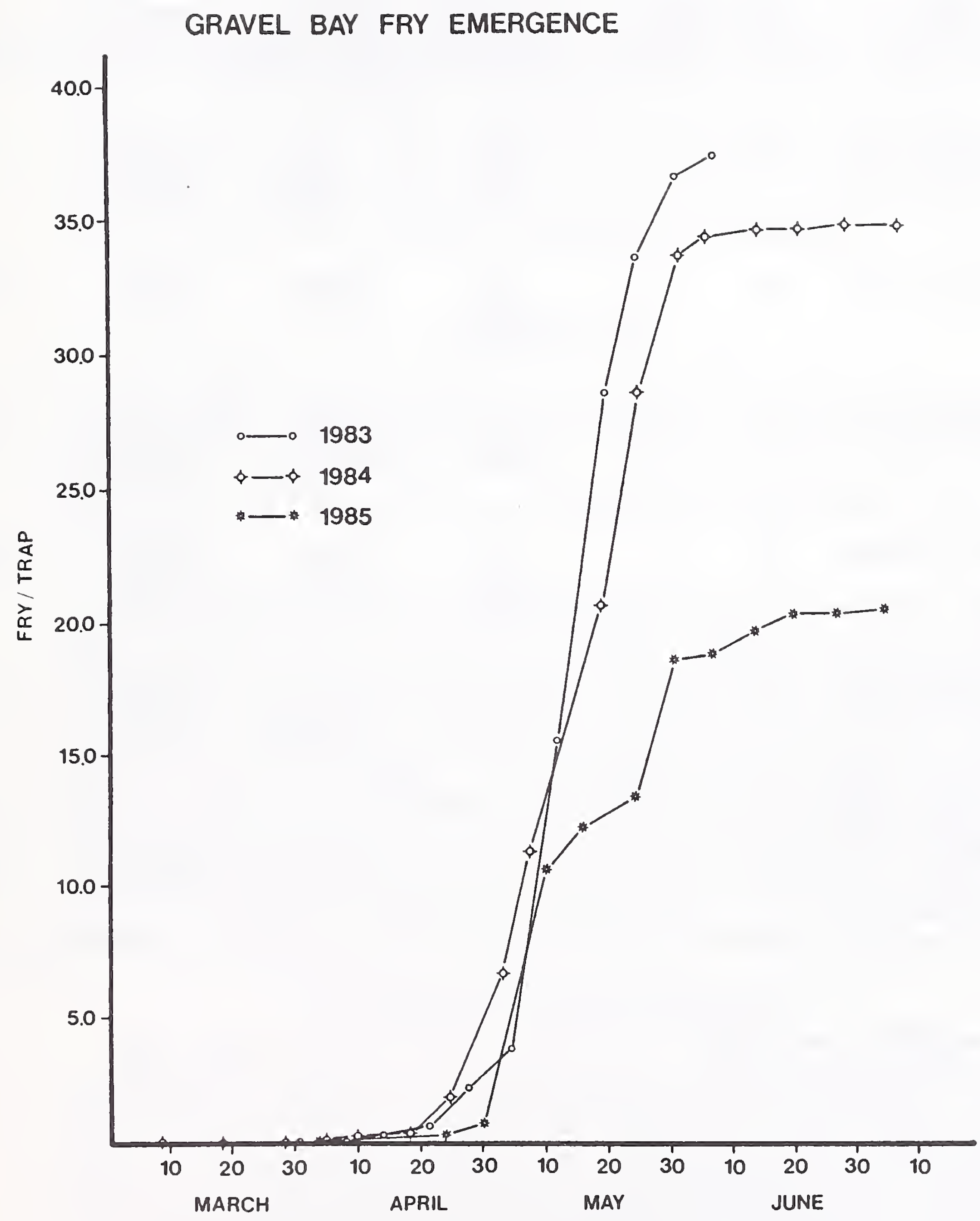


Figure 12. Timing and relative abundance of fry emergence from spawning areas below minimum pool, at Gravel Bay on Flathead Lake, from 1983-1985.

Table 7. Potential egg deposition, fry emergence, and survival at Gravel Bay, Flathead Lake in 1985.

Depth Interval	No. Redds		Mean catch per trap s=variance	Expanded total emergence	Potential egg deposition	Survival %
	Total	Trapped				
2,860-2,865	27	2	0.2 n=5	54 (<1%)	28,080 (8.6%)	0.1
2,865-2,870	64	3	13.5 n=6 s=19.4	8,640 (12.9%)	66,560 (20.3%)	13.0
2,870-2,875	103	8	28.1 n=10	28,943 (43.2%)	107,120 (32.8%)	27.0
2,875-2,880	103	8	26.4 n=10 s=29.2	27,192 (40.6%)	107,120 (32.8%)	25.4
2,880-2,885	17	0	13* n=0	2,210 (3.3%)	17,680 (5.4%)	12.5
TOTAL	314	21		67,039	326,560	20.5

* estimate - see text

River in 1983, and 15% in Brenneman's Slough. These estimates were all derived from drift net catches.

A number of factors can contribute to errors in estimates of survival to emergence. Incomplete fertilization, redd superimposition, incomplete redd construction, egg retention, and predation can reduce potential egg deposition. The number of spawners at Gravel Bay has not been accurately counted, and so the number of females building redds, or their residence time, is not known. The efficiency of emergence traps used in Flathead Lake has not been established. The variance in average catch per trap is very high with a few traps catching the majority of emergent fry in each depth zone. Predation inside the traps is also possible, though we found few kokanee fry in the stomachs of trapped yellow perch (*Perca flavescens*) and cottids.

Fry Condition

The length of fry collected at Gravel Bay varied from 21.0 to 25.5 mm. Mean length was 24.2 mm, and 85% of fry were between 23.5 and 25.5 mm. Fry weight varied between .061 g and .113 g, with a mean of 0.091 g (Fig. 13). Condition of these fry ($K = \text{weight} \times 10^5/\text{length}^3$) varied between 0.535 and 0.827, with mean of 0.642.

This figure does not vary significantly from the mean condition of Gravel Bay fry in 1983 and 1984 (Decker-Hess and Clancey, 1984; Decker-Hess and McMullin, 1983). Length of late emerging fry sampled June 19 was less than earlier emergents (mean = 21.4 n = 10) but their mean condition (.676) was not below the overall mean. The condition factor is influenced by the extent to which the yolk sac is absorbed. Fry condition was negatively correlated with depth of their redd at Gravel Bay in 1983 (Decker-Hess and McMullin, 1983). Our sample of late emerging fry was from a deep redd (2866.3 feet), and so their small size could have been related to adverse incubation environment, e.g. low dissolved oxygen.

Intragravel Movement Experiment

The results of the two intragravel migration experiments are summarized in Table 8. These experiments were designed to test the ability of fry to move through substrate under ideal conditions. The 10% fines channel was replicated in each experiment, because this gravel composition is most conducive to fry movement. The distribution of sac-fry in the 10% fines channels at the end of the 4-day experiments varied considerably between replicates and between experiments. The mean downstream migration distance ranged from 56.9 to 111.2 cm in the two replicates of the first experiment, and 147.0 to 163.3 cm in the second experiment. The percentage of fry moving downstream, upstream and not migrating also varied considerably between replicates and between

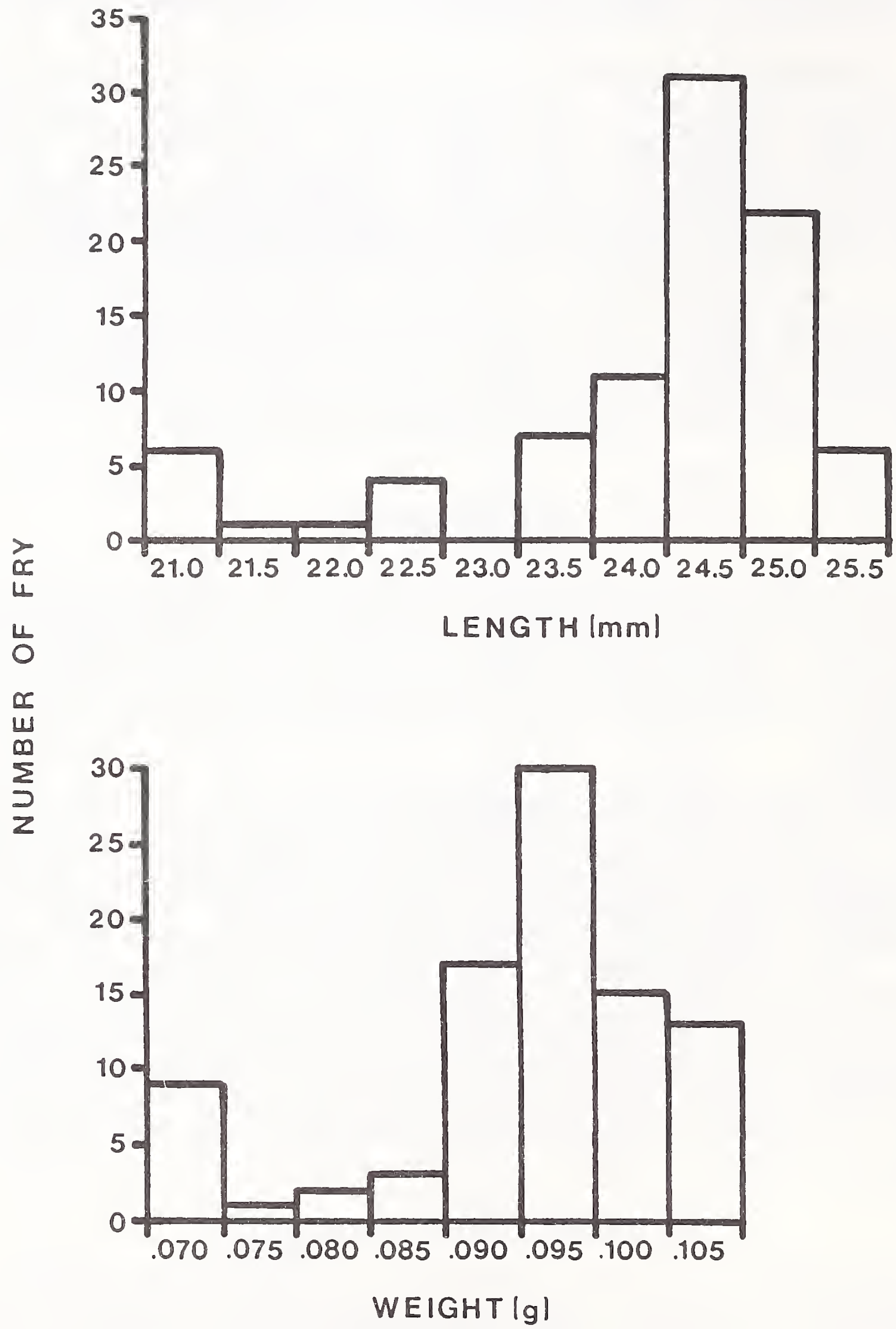


Figure 13. The distribution of the weight and length of kokanee fry emerging from Gravel Bay redds in 1985.

Table 8. Results of an experiment to measure the ability of kokanee fry to move through substrate of varying size composition in hatchery channels.

Experiment	% Fines	Replicate	No. fry planted	Percent of Fry Moving up	down	0	Mean downstream movement cm/day
I	10	A	95	7.4	40.0	52.6	14.2
I	10	B	78	23.1	61.5	15.4	27.8
II	10	A	78	5.1	94.9	0.0	40.8
II	10	B	107	2.8	73.8	23.4	36.8
I	20		109	2.8	34.9	62.4	24.1
II	20		141	0.0	70.9	29.1	28.7
I	30		65	1.5	90.8	7.7	13.6*
II	30		97	3.1	92.8	4.1	29.4*
I	40		74	0.0	89.2	10.8	15.7*

* fry moved across gravel surface due to standing water, so no fry at end of channel were included in this figure.

experiments. Our inability to standardize flow rates through the channels due to siltation of the hatchery water supply, contributed to variation in fry migration. As we would expect, mean migration distance in the 10% channels exceeded that in the 20% fines channel. Mean migration distance was also greater in the second experiment than in the first, due to the increased maturity of sac-fry. The percentage of fry not migrating was greater in the 20% fines channel for both experiments. In general for all gravel compositions very few fry moved upstream; those that did moved only a short distance. In both experiments on the 30% fines channel and the single experiment in the 40% fines channel we could not prevent water from flowing over the surface of the gravel at the flows necessary. Sac-fry in these channels moved vertically to the gravel surface and then downstream, with a large proportion reaching the end of the channel within four days.

These results support the following conclusions: In 10-20% fines substrate, kokanee sac-fry are capable of sustained intragravel movements of at least 30 cm per day. In high fines (30-40%) substrate, sac fry tend to move vertically to the surface and then may move over the gravel surface, if flowing water is available. All movements are characteristically downstream. Any movement within the substrate depends on standing or flowing interstitial water to prevent desiccation.

These results imply that recruitment from kokanee redds constructed above minimum pool is possible where consistent groundwater discharge wets the substrate and/or provides surface flows to allow fry movements. We have consistently observed that eggs survive winter drawdown and hatch successfully where groundwater keeps redds wetted. Our experiments show that at least 50-75% of sac-fry attempt to move through the substrate. At six of the nine lakeshore spawning areas where we measured substrate size composition, fines comprised about 10% of the material. Where surface flows of groundwater exist, or where stream discharge spreads over the beach such as Thurston, Pineglen, Dr. Richards, and Crescent Bay, sac fry may reach the lake, even where a higher percentage of fines in the substrate inhibits movement through gravel. In fact we have observed schools of newly emergent kokanee fry in the littoral zone at Thurstons and Pineglen, where no redds were constructed below minimum pool.

Further experiments should be conducted to confirm the effect of increasing fines in the substrate and to determine the minimum flows required to allow intragravel movement. Other research with salmonids has documented that substrate composition, dissolved oxygen, and redd exposure influence emergence movements and timing. Bams (1969) reported that emerging fry are more likely to exhibit positive rheotaxis, i.e. to swim upstream out of redds in streams. In similar experiments, Decker-Hess and McMullin (1983) reported that intragravel movement and survival decreased as percent fines increased. Other factors need to be considered: are

alevins in groundwater seeps pre-stressed by low oxygen tension, and thus prone to early emergence and poor condition? Do intragravel migrations place a stressful, high energy demand on sac-fry, reducing their mobility and feeding success once they reach the lake?

KOKANEE FOOD AVAILABILITY

We monitored the abundance of the principal planktonic crustaceans to detect changes in the food base of kokanee, should they occur. Such changes might logically be expected as the introduced opossum shrimp (Mysis relicta) becomes established. Though mysids were collected incidentally as early as 1981 in Flathead Lake, they were not measurably abundant at three index stations until 1984. In June, mysid density varied from $0.02/m^2$ to $0.19/m^2$, and there is evidence that the population in Flathead Lake is increasing rapidly. Cladocerans have become less abundant in other large lakes presumably due to mysid predation or competition (Rieman and Falter, 1981). These kinds of changes could affect the growth and survival of kokanee, which feed preferentially on large cladocerans during their growing season.

Average temperatures in the upper 15 m of the water column, at the Bigfork monitoring station, were up to several degrees cooler in 1984 than during the period 1980 to 1983. The maximum average temperature in 1984 was 12.5°C, whereas in the previous four years it ranged from 13.6 to 17.9°C. The lake was thermally stratified from early July through August.

Three copepod and four cladoceran species were the principle zooplankton collected in 1984. The copepods were Epischura nevadensis, Cyclops bicuspidata, and Diaptomus ashlandi. The cladocerans were Leptodora kindtii, Daphnia thorata, Daphnia longiremis, and Bosmina longirostris. Diaptomus and Cyclops comprised an average of 73.4%, by number, of the zooplankton community; Daphnia and Bosmina composed 26.4% of the total. Composition was similar to that observed in 1980, 1981, and 1983. Total zooplankton density in 1984, 10.9/liter, was identical to that seen in 1983. The density of each species, and its abundance relative to the other principal zooplankton, are detailed in Appendix B.

Of the four species identified by Leathe and Graham (1982) as important kokanee food, three decreased in density and one increased between 1983 and 1984 (Table 9). They found that D. thorata made up 70-90% of the diet of all ages of kokanee, when it was available in spring and summer. Age III+ fish ate Diaptomus in winter, and Leptodora and Epischura in late summer and fall. The availability of Daphnia in early summer, when age 0+ kokanee reach the limnetic zone, may be crucial to young of the year survival. No delay in the Daphnia "bloom" has been observed during the four years of this study. The average density of all four principle prey species was lower in 1984 than in 1981 and 1982. These annual fluctuations may reflect variations in lake productivity, or other natural variation in zooplankton abundance. Samples taken from a single station are not sufficient to define a lakewide trend.

Table 9. Average density of the principal kokanee salmon prey species in the upper 15 meters of Flathead Lake at Bigfork during the period April through October for the years 1980-1984. *D. thorata* and *Diaptomus* are expressed as number/liter and *Epischura* and *Leptodora* are expressed as number/m^3.

	1980	1981	1982	1983	1984
D. thorata	3.2	3.4	1.5	0.9	1.1
Diaptomus	12.4	16.9	17.7	7.3	5.2
Epischura	--	34.5	39.0	25.3	13.6
Leptodora	--	7.8	14.8	6.4	3.6

DISPERSION AND SPAWNING DESTINATION OF THE WINTER KOKANEE AGGREGATION IN SKIDOO BAY

During the winter, kokanee salmon that aggregate in Skidoo Bay, on the southeast corner of Flathead Lake, attract an intensive fishery, especially when the bay freezes enough to support ice fishing. This fishery became popular in the late 1970's. Creel surveys conducted during this period showed high catch rates (Fredenberg & Graham, 1982) and the possibility of overharvesting kokanee. Our experiments were designed to show when this aggregation dispersed, pattern of dispersion in the lake, and the spawning destinations of tagged fish.

Tag returns in March and April came only from Skidoo Bay. the majority of recoveries in June came from Big Arm (Figure 14), but some were recovered from Woods Bay to Bigfork, and on the northwest shore from Angel Point to Lakeside. In July tagged fish were caught, primarily, in these latter two areas, as well as along the eastern shore of Wildhorse Island and in Rollins Bay. August and September recoveries came mostly from the area between Woods Bay and Bigfork. A total of 128 tags were returned by anglers, between April and September, 1984.

Kokanee in Skidoo Bay apparently remain aggregated until the end of April. The reason for this large concentration of fish has not been clarified, though food availability is a likely factor. The fish disperse rapidly throughout the lake by June. They are present in Big Arm Bay until the shallow western extent warms beyond their tolerance limits. River-run fish congregate along the northeastern shore of the lake in August, before moving into the river. Though some fish enter the river by mid-August, the runs do not develop strongly until September. Tag return data is summarized in Appendix C.

Tagged spawning kokanee were recovered from McDonald Creek, 60 miles up from the lake, in the first week of October. Other recoveries in river spawning areas occurred through November, and as late as December 7. Tagged lakeshore spawners were observed in Somers Bay and Woods Bay in the first two weeks of November.

The principle conclusion from the foregoing tag return information is that a wide variety of spawning stocks contribute to the Skidoo Bay aggregation. The intensive winter fishery harvested virtually the entire range of spawning stocks. In any mixed stock fishery, however, weaker components are more likely to be overharvested. Very few (2) tagged fish were observed at the principle lakeshore spawning areas. Lakeshore spawners made up only 2-3% of the total 1984 spawning run, so the probability of tagging a lakeshore spawner the previous spring was low. It is possible that these weak lakeshore "stocks" are overharvested during both the winter and summer fishery. Interpretation of tag return data must be tempered with the assumption that recoveries

are related to the distribution of fishing pressure in the lake. We have no information on how the integrity of schools observed in Skidoo Bay during winter is maintained through the spring and summer. It seems most likely that schools and stocks move and mix randomly moving around the lake during the summer, and aggregate at points where food availability and temperatures are favorable.

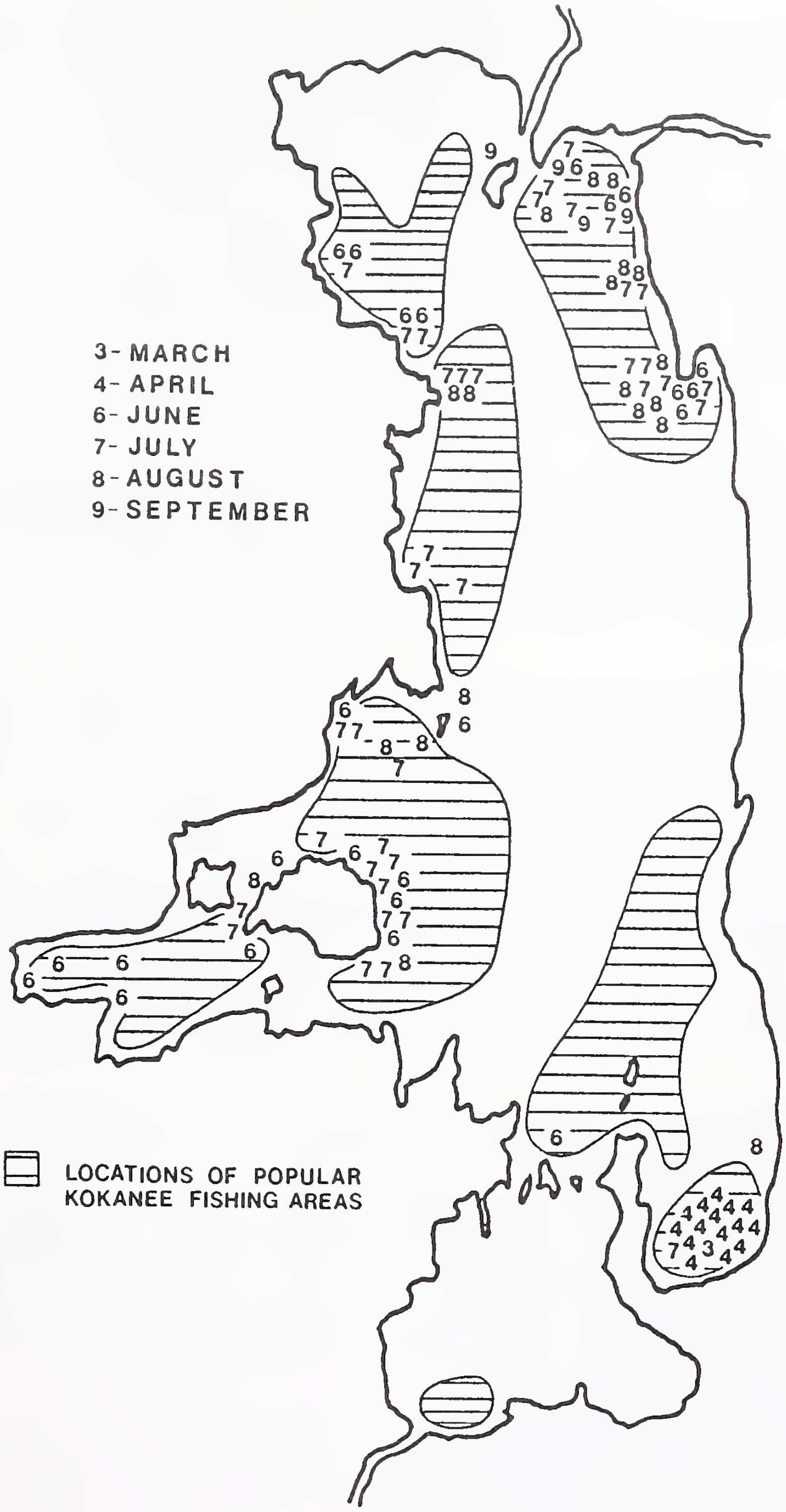


Figure 14. Date and location of tagged kokanee returns from Flathead Lake fisheries from March through September, 1984.

CONCLUSIONS

Surveys during the past four spawning seasons have shown that 600-1,200 kokanee redds were built each year, primarily at ten sites in Skidoo Bay, Gravel Bay, Blue Bay, and Woods Bay on the east shore of Flathead Lake, and at Crescent Bay on the west shore. We were unable to count lakeshore spawners, but given the ratio of fish to redds in Flathead River we assume the lakeshore run consisted of 2-3,000 fish. This figure does not include returns to Somers hatchery, from which brood stock is taken. Spawning began along the lakeshore in mid-October, peaked in mid-November, and continued until mid-December. The return to Swan River has consistently been about 1,000 spawners.

It is clear that kokanee spawn on a much smaller scale at present compared with the early 1950's, when the earliest surveys were done by Montana Department of Fish, Wildlife and Parks. At that time, concentrations of spawning kokanee were observed at several east and west shore sites, and in Polson Bay, where spawning no longer occurs.

We have characterized lakeshore spawning habitat in terms of elevation, substrate size, groundwater discharge and dissolved oxygen. This will allow quantification of potential, i.e. unused, spawning habitat around Flathead Lake. Assisted by studies subcontracted to the Geology Department of the University of Montana, we have described the groundwater regime in lakeshore spawning areas, and investigated changes in the regime induced by lake drawdown. We found that the groundwater table stayed elevated, and groundwater seeps persisted during drawdown at many shoreline spawning sites. All spawning sites are in zones of groundwater discharge or at the mouths of streams.

We have measured the tolerance of kokanee eggs and alevins to drawdown exposure by sampling exposed natural redds and artificially planted eggs. Recently fertilized eggs die within 12 hours of exposure, but the mean tolerance of eyed eggs is approximately 40 days in moist gravel. Sampling of natural redds showed great range in survival due to local variation in substrate composition and groundwater discharge. Experiments with eggs planted in various substrate environments, and sampled at greater frequency, will be conducted to more accurately measure tolerance of exposure due to drawdown. Fry emerged between mid-April and the end of June. The peak of emergence at two deep sites was in early May. Egg-to-fry survival was estimated to be 20% in 1985.

Current management goals for Flathead Lake kokanee include increasing spawning escapement and reproductive success, particularly in river-spawning stocks. The stability of the fishery would be enhanced by successful reproduction at diverse spawning areas on the lake and in its tributaries. We monitored the sport harvest in 1984 to insure that the kokanee population was not over-exploited. Results of the creel survey will be published

under separate cover. Tagging studies of the kokanee that aggregate in Skidoo Bay during the winter and spring showed that fish from many spawning areas comprise the aggregation. Concentrated fishing pressure, such as the Skidoo ice fishery, could overexploit numerically weak stocks and should be monitored.

The expanding mysid shrimp population, and its effect on the zooplankton community in Flathead Lake, will be followed closely for the remaining years of this study. The mysid population, which has been projected to reach densities of $1{,}000/m^2$ within two years, could reduce the abundance of cladocerans during spring and summer. We will direct sampling to detect changes in cladoceran abundance, and changes in the growth and survival of young of the year kokanee during the growing season. Changes in the capacity of the lake to support fish populations are of particular relevance to efforts to mitigate previous losses in fisheries due to hydropower development.

LITERATURE CITED

Alvord, W. 1975. History of the Montana Fish and Game. Montana Department of Fish and Game, Helena, Montana, USA.

Bams, R.A. 1969. Adaptations of sockeye salmon associated with incubation in stream gravels. pp. 71-87 In: T.G. Northcote (Editor) Symposium on salmon and trout in streams. University of British Columbia, Vancouver, B.C.

Bjornn, T.C. 1957. A survey of the fishery resources of Priest and Upper Priest Lakes and their tributaries, Idaho Dept. Fish Game, Compl. Rep. No. F-24-R, 176 p.

Bowler, B. 1979. Kokanee spawning trends in Pend Oreille Lake. Idaho Department of Fish and Game Job Performance Report, F-73-R-1, Job II. p. 57-77.

Decker-Hess, J. and P. Clancey. 1984. Impacts of water level fluctuations on kokanee reproduction in Flathead Lake. Annual report to the Bonneville Power Administration Contract DE AI79-83BP39641, Project No. 81S-5. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana, USA.

Decker-Hess, J. and P.J. Graham. 1982. Impacts of water level fluctuations on kokanee reproduction in Flathead Lake. Montana Department of Fish, Wildlife and Parks, Kalispell.

Decker-Hess, J. and Steve L. McMullin. 1983. Impacts of water level fluctuations on kokanee reproduction in Flathead Lake. Montana Department of Fish, Wildlife and Parks. 172 pp.

Domrose, R. 1968. Kokanee redd exposure and hatching success in relation to receding Flathead Lake levels. Montana Department of Fish, Wildlife and Parks, Kalispell. 2 pp.

Foerster, R.E. 1968. The sockeye salmon (Oncorhynchus nerka), Journal of the Fisheries Research Board of Canada. Bulletin 162. 422 pp.

Fraley, J.J. 1984. Effects of the operation of Hungry Horse dam on the kokanee fishery in the Flathead River System. Annual Progress Report FY 1984. Fisheries Research and Special Projects Bureau, Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Fraley, J.J. and J. Decker-Hess. 1985 (in press). Effects of stream and lake regulation on reproductive success of kokanee salmon in the Flathead System, Montana.

Fraley, J.J. and P.J. Graham. 1982. The impact of Hungry Horse Dam on the fishery of the Flathead River. Completion report submitted to the Bureau of Reclamation. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana, USA.

Fraley, J.J., and S.L. McMullin. 1983. Effects of the operation of Hungry Horse Dam on the Kokanee Fishery in the Flathead River System. Annual report to the Bonneville Power Administration, Contract DE AI79-83BP39641, Project No. 81S-5. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana, USA.

Fredenberg, W. and P.J. Graham. 1982. Flathead River fisherman census, U.S. Environmental Protection Agency. Montana Department Fish, Wildlife and Parks, Kalispell.

Graham, P.J. and W. Fredenberg. 1982. Flathead Lake fisherman census. Report submitted to the U.S. Environmental Protection Agency. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana, USA.

Graham, P.J., D. Read, S. Leathe, J. Miller, and K. Pratt. 1980. Flathead River basin fishery study. Montana Department of Fish, Wildlife and Parks. Kalispell, Montana, USA.

Graham, P., R. Penkal, S. McMullin, P. Schladweiler, H. Mays, V. Riggs, and R. Klaver. 1981. Montana recommendations for fish and wildlife program, submitted to Pacific Northwest Electric Power and Conservation Planning Council. Montana Department of Fish, Wildlife and Parks; Confederated Salish and Kootenai Tribes; and U.S. Fish and Wildlife Service.

Hanzel, D.A. 1964. Evaluation of Kokanee Spawning and Population Density in Flathead Lake and Tributaries. Montana Dept. of Fish and Game. Job Completion Report F-7-R-12, Job II. 10pp.

Hanzel, D.A. 1977. Angler pressure and gamefish harvest estimates for 1975 in the Flathead River system above Flathead Lake. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana, USA.

Hanzel, D.A. 1984. Measure annual trends in recruitment and migration of kokanee populations and identify major factors affecting trends. Montana Department of Fish, Wildlife and Parks, Job Performance Report F-33-R-18, Job No.:I-b.

Hart, J.L. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada Bulletin 180. Ottowa.

Hassemer, P.F. and B.E. Rieman. 1979. Kokanee life history studies in Priest Lake - spawning evaluation. Idaho Department Fish and Game, Job Performance Report F-73-R-1, Job III. p.89-105.

Hassemer, P.F. and B.E. Rieman. 1980. Coeur d'Alene Lake spawning evaluations. Idaho Department Fish and Game, Job Performance Report F-73-R-2, Job III. p.89-95.

Jeppson, P. 1955. Evaluation of spawning areas in Lake Pend Oreille and tributaries upstream from Albeni Falls Dam in Idaho, April, 1954 - May 31, 1955, including supplemental information on the life hstory of kokanee. Idaho Department of Fish and Game, Job Completion Report F-3-R-4 and F-3-R-5, Work Plan 2. 36 pp.

Jeppson, P. 1960. Evaluation of kokanee and trout spawning areas in Pend Oreille Lake and tributary streams. Idaho Department Fish and Game, Job Progress Report F-3-R-10.

Kimsey, J.B. 1951. Notes on kokanee spawning in Donner Lake, California, 1949. California Fish and Game. 37(3):273-279.

Leathe, S.A. and P.J. Graham. 1982. Flathead Lake fish food habits study. Montana Department of Fish, Wildlife and Parks. Kalispell, Montana, USA.

Lee, D.R. and J.A. Cherry. 1978. A field exercise on groundwater flow using seepage meters and min-piezometers. Journal of Geology Education. 27:6-10.

Lindsay, R.B. and S.L. Lewis. 1975. Population dynamics of kokanee salmon in Odell Lake, December 1, 1974 - June 30, 1975. Oregon Department of Fish and Wildlfife, Job Progress Report F-71-R-11, Jobs 10 and 11. 12 p.

Lotspeich, F.B. and F.H. Everest. 1980. Reporting and interpreting textural composition of spawning gravel. Unpublished report USDA Forest Sciences Laboratory, Corvallis, Oregon.

McMullin, S.L. and P.J. Graham. 1981. The impact of Hungry Horse Dam on the kokanee fishery of the Flathead River. Report submitted to the Bureau of Reclamation. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana, USA.

McNeil, W.J. 1968. Survival of pink and chum salmon eggs and alevins. pp. 101-117 IN: T.G. Northcote, Editor. Symposium on salmon and trout in streams. University of British Columbia, Vancouver, Canada.

Mead, R.W. and W.L. Woodall. 1968. Comparison of sockeye salmon fry produced by hatcheries, artificial channels and natural spawning areas. International Pacific Salmon Fisheries Commission. Progress Report No. 20.

Montana Department of Fish and Game. 1976. Estimated man-days of fishing pressure by region for the summer and winter season, May 1975 - April 1976. Montana Department of Fish and Game. Helena.

Montana Power Company. 1976. Application of the Montana Power Company for a new license for the Kerr Project. To: The Federal Energy Regulatory Commission.

Pfeifer, Robert L. 1978. Evaluation of the natural reproduction of kokanee (Oncorhynchus nerka) in Lake Stevens, Washington, as related to the lake limnology and basing. University of Washington, Seattle. M.S. Thesis.

Potter, D.S. 1978. The zooplankton of Flathead Lake: An historical review with suggestions for continuing lake resource management. Ph.D. Diss., University of Montana, Missoula, USA.

Rieman, B.E. and C.M. Falter. 1981. Effects of the establishment of Mysis relicta on the macrozooplankton of a large lake. Transactions of the American Fisheries Society.

Robbins, O. 1966. Flathead Lake (Montana) fishery investigations. 1961-1964. Bureau of Sports Fisheries and Wildlife, Technical Paper. 45 pp.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184. Ottawa.

Shirazi, M.A. and W.K. Seim. 1979. A stream systems evaluation - an emphasis on spawning habits of salmonids. USEPA/EPA-600/3-79-109. Corvallis Environmental Research Laboratory, Oregon.

Stanford, J.A., T.J. Stuard, J.D. Coulter, and F.R. Hauer. 1981. Limnology of the Flathead River-Lake ecosystem, Montana. Annual Report, Flathead Research Group, University of Montana Biological Station, Bigfork, Montana. 331 pp.

Stefanich, F.A. 1953. Natural reproduction of kokanee in Flathead Lake and tributaries. Montana Department of Fish and Game, Job Completion Report F-7-R-2, Job III-A. p.69-74.

Stefanich, F.A. 1954. Natural reproduction of kokanee in Flathead Lake and tributaries. Montana Department of Fish and Game, Job Completion Report F-7-R-3, Job III-A. 10p.

Stober, Q.J., R.W. Tyler, C.E. Petrosky, K.R. Johnson, C.F. Cowman, Jr., J. Wilcock, and R.E. Nakatani. 1979. Development and evaluation of a net barrier to reduce entrainment loss of kokanee from Banks Lake. Final Report, April 1977 - March 1979 to U.S. Bureau of Reclamation, Contract No. 7 -07-10-50023, University of Washington, Fisheries Research Institution. FRI-UW-7907. 246 pp.

Stober, Q.J., R.W. Tyler, C.F. Cowman, Jr., J. Wilcock, and S. Quinnell. 1979. Irrigation drawdown and kokanee salmon egg to fry survival in Banks Lake. Final Report. April 1979 - September 1979, to U.S. Bureau of Reclamation, Contract No. 7-07-10-50023, University of Washington, Fisheries Research Institution. FRI-UW-7913. 73 pp.

Whitt, C.R. 1957. Age and growth characteristics of Lake Pend Oreille kokanee, 1956. Idaho Department of Fish and Game Annual Summary Report F-3-R-6 and F-3-R-7, Work Plan 2. 20pp.

Woessner, W.W. and C.M. Brick. 1983. Groundwater investigations related to the location and success of kokanee salmon spawning, Flathead Lake, Montana: Preliminary Results, April, 1982 - June 1983. Draft Report. University of Montana, Missoula. 125 pp.

Woessner, W.W. and C.M. Brick. 1984. Hydrogeologic conditions during kokanee spawning, egg incubation and fry emergence at selected sites, Flathead Lake, Montana. University of Montana, Missoula.

Woessner, W.W., C.M. Brick, and J. Moore. 1985. Spawning site hydrogeology on-shore water table fluctuations during lake stage rise and fall, and the effects of Kerr Dam operation on shoreline habitat, Flathead Lake, Montana, University of Montana - Department of Geology.

APPENDIX A: Supplementary Tables & Figures

Table A-1. Comparison of substrate size composition from sieve analysis, and analysis of photographs taken before and after disturbance. The six sites at Thurstons, in Skidoo Bay.

		>50.8 mm	50.8 mm to 16 mm	16 mm to 6.35 mm	<6.35 mm
Site 1	Sieve analysis	8.6	50.0	29.5	11.9
	Photo before	7.5	54.2	23.4	14.9
	Photo after	15.7	57.8	21.6	4.9
Site 2	Sieve analysis	29.5	44.2	16.7	9.6
	Photo before	19.1	50.9	15.5	14.5
	Photo after	24.5	51.9	20.8	2.8
Site 3	Sieve analysis	14.5	51.7	24.9	8.9
	Photo before	17.0	36.6	33.0	13.4
	Photo after	22.7	45.5	24.5	7.3
Site 4	Sieve analysis	0	13.3	25.6	61.1
	Photo before	0	16.0	24.0	60.0
Site 5	Sieve analysis	18.0	52.6	25.7	3.7
	Photo before	0	57.0	32.7	10.3
	Photo after	17.9	55.7	21.7	4.8
Site 6	Sieve analysis	2.7	40.1	53.0	4.2
	Photo before	2.0	21.5	56.1	20.4
	Photo after	2.0	37.6	39.6	20.8

Table A-2. Comparison of mean particle size (d_g), Fredle index (f_i) and percent fines (<6.4 mm) from sieved samples, and photographs taken before and after excavation.

Sample	Analysis	d_g mm	f_i	S_o	% <6.4 mm
483 - 484	Sieve	17.2	10.2	17.2	12
	Photo before	16.7	9.8	16.6	15
	Photo after	22.4	14.0	22.4	5
479 - 480	Sieve	22.3	13.0	22.2	10
	Photo before	19.3	11.1	19.3	14
	Photo after	26.6	16.2	26.6	3
481 - 482	Sieve	19.5	11.7	19.6	9
	Photo before	17.4	9.9	17.5	13
	Photo after	21.6	13.0	21.6	7
489 - 490	Sieve	4.9	2.5	4.9	61
	Photo before	5.3	2.8	5.4	60
	Photo after				
487 - 488	Sieve	22.8	14.3	22.8	4
	Photo before	14.7	10.0	14.6	10
	Photo after	22.7	14.1	22.6	5
485 - 486	Sieve	17.3	11.0	17.3	4
	Photo before	10.8	6.1	10.8	10
	Photo after	12.1	7.0	12.2	5

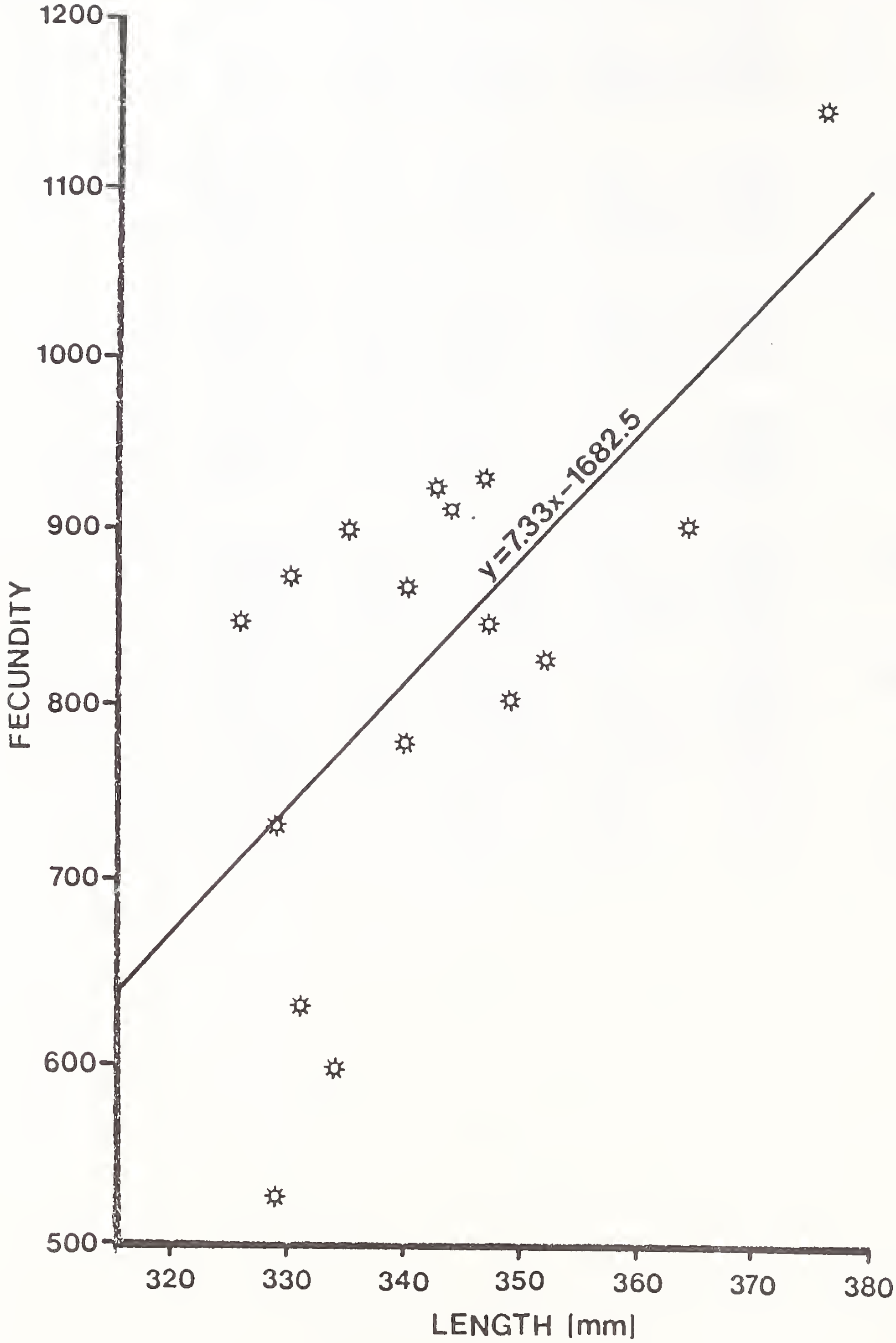


Figure A-3. The relationship between female fish length and fecundity, (Fraley, unpublished data 1982).

Appendix A-4. Groundwater chemistry profiles at spawning areas on Flathead Lake.

Location	Sample	Date	Bicarbonate measured	Chloride	Sulfate	Nitrate-n	Calcium	Magnesium	Sodium	Potassium	Total dissolved solids
Orange house	211	2/22	199.6	0.75	9.9	0.133	50.2	10.3	3.3	1.4	276.1
	214	1/21	189.9	0.75	2.8	0.190	44.4	9.8	2.6	1.2	252.3
	214	2/22	182.4	0.86	5.5	0.164	44.4	9.2	3.1	1.3	247.5
	214	3/22	187.3	0.73	6.8	0.145	45.6	9.7	2.7	1.2	254.6
	219	1/21	154.5	0.45	2.0	0.190	36.9	7.3	2.2	1.0	205.2
	219	2/22	140.5	0.75	25.3	0.192	42.7	6.9	2.4	1.0	220.5
Woods Bay West	064	1/21	109.7	1.13	4.0	0.094	24.5	7.2	1.8	1.2	149.6
	064	2/22	111.2	1.33	8.9	0.095	25.9	7.8	2.6	1.1	159.2
	076	3/22	117.3	0.50	4.0	0.231	23.2	8.8	3.1	1.2	159.1
Woods Bay East	REDD	1/21	153.6	0.63	2.1	0.323	30.3	10.6	2.5	1.2	202.4
Deep Bay		1/21	226.4	0.63	3.5	0.142	54.6	11.8	2.1	0.7	300.4
	86	2/22	222.4	0.68	10.1	0.156	56.0	11.8	2.7	0.6	305.0
Pineglen	022	1/21	161.9	1.50	2.4	0.42	34.8	10.8	2.5	1.0	216.8
	026	2/22	213.9	1.34	6.4	0.197	46.0	14.3	3.4	1.5	295.7
	034	3/22	127.6	1.60	5.1	0.339	27.4	8.4	3.2	1.2	175.9
Thurston's	202	1/21	181.2	1.00	7.8	0.278	36.8	12.8	4.9	1.2	246.9
	202	2/22	178.8	1.00	7.4	0.195	38.1	12.4	1.9	0.4	240.9
	205	1/21	165.2	1.17	6.8	0.169	33.6	11.3	4.8	1.2	224.8
	205	2/22	166.5	0.79	6.8	0.100	34.5	11.1	5.3	1.3	226.7
	205	3/22	165.6	0.54	8.3	0.083	34.1	11.4	5.1	1.3	226.8
	208	1/21	167.3	0.54	6.5	0.130	33.9	11.3	4.7	1.2	226.0
	208	2/22	167.6	0.57	6.8	0.085	33.6	11.4	5.2	1.3	226.9
Table Bay	86	2/22	364.5	4.3	15.7	0.664	72.7	27.1	11.5	0.9	501.7
Hatchery		2/22	190.4	0.29	2.0	0.041	36.8	14.8	3.9	0.7	249.1
Big Arm	001	3/22	117.6	1.52	21.4	0.293	33.2	7.9	3.2	0.8	186.9

Appendix A-5. The distribution of apparent velocity and dissolved oxygen of groundwater in redds at five elevation ranges, expressed as percent of redds in each range.

Elevation		Dissolved Oxygen										
n	Range (ft)	0-2	2.1-3	3.1-4	4.1-5	5.1-6	6.1-7	7.1-8	8.1-9	9.1-10	10.1-11	11.1-12
65	2,885-90	4.6	6.2	7.7	1.5	3.1	0	7.7	16.9	30.8	21.5	0
41	2,880-84.99	0	0	2.4	0	0	7.3	7.3	19.5	36.6	24.4	2.4
15	2,875-79.99	0	0	0	0	0	0	0	13.3	40.0	46.7	0
19	2,870-74.99	0	0	0	0	0	10.5	0	14.8	31.6	26.3	15.8
6	2,865-69.99	0	0	0	0	0	16.7	0	0	16.7	50.0	16.7
		Apparent Velocity (cm/h)										
		.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	>1.0
65	2,885-90	9.2	16.9	16.9	18.5	6.2	7.7	3.1	3.1	0	0	18.5
<11	2,880-84.99	17.1	22.0	26.8	22.0	7.3	0	2.4	0	0	0	2.4
15	2,875-79.99	6.7	33.3	26.7	26.7	6.7	0	0	0	0	0	0
19	2,870-74.99	31.6	36.8	10.5	15.8	5.3	0	0	0	0	0	0
6	2,865-69.99	16.7	50.0	33.3	0	0	0	0	0	0	0	0

Appendix Table A-6. Egg and alevin survival in natural redds, above minimum pool, at nine lakeshore spawning areas.

Location	Redd Number	Elevation (m)	Date Sampled	Date Exposed	Number days exposed prior to sampling	Percent survival Eggs	Percent survival Alevins	Stage of Development	Total Number Eggs	Total Number Alevins
Woods Bay East	280	86.16	1/30/85	1/9/95	22	59	—	100% eyed	231	—
	281	86.86	1/30/85	12/28/84	34	<1	—	100% eyed	149	—
	300	84.76	3/1385	12/28/84	34	assume 0		nothing found		
	301	85.20	3/13/85	1/30/85	42	50	—	100% eyed	100	—
Woods Bay West	061	85.50	3/13/85	1/19/85	54	0	—		15	—
	062	84.30	3/13/85	2/24/85	20	0	4	51% hatched	50	52
	063	85.50	3/13/85	1/17/85	55			nothing found		
	064	85.70	3/13/85	1/14/85	58			frozen		
	076	84.60	3/13/83	2/16/85	53			nothing found		
Pineglen	019	86.40	3/13/85	1/6/85	66	0	—	—	—	—
	021	86.40	1/30/85	1/6/85	25	4	—	100% eyed	99	—
	022	86.60	1/30/85	1/2/85	29	0	—	100% eyed	114	—
	022	86.60	3/13/85	1/2/85	70	0	—	(eyed)	—	—
	041	83.7	3/13/85	—	0	-	±20	100% hatched	—	±100
		85.04	3/7/85	2/10/85	36	—	100	100% hatched	—	—
		85.04	3/13/85	2/10/85	32	—	0			numerous
		84.74	3/7/85	2/14/85	22	0	0	50% hatched	—	—
		84.73	3/7/85	2/14/85	22	—	100	100% hatched	—	—
		84.46	3/13/85	2/19/85	25	100	100	33% hatched	20	10
		84.23	3/7/85			—	100	100% sac fry	—	—
Dr. Richards	266		3/13/85			0	—		—	—
	268		3/13/85			0	--		—	—
	270		3/13/85			—	--	nothing found		
	creek-side		3/13/85			—	—	nothing found		
Orange House	212	85.70	1/29/85	1/14/85	16	96	-		221	—
	213	86.10	3/13/85	1/10/85	63	0	100	33% hatched	10	20
	214	86.90	1/29/85	12/28/85	34	—	100		125	—
	215	86.60	1/30/85	1/2/85	29	--	100		91	—
	216	86.90	3/13/85	12/28/85	76	50	100	95% hatched	2	40
	218	86.90	1/30/85	12/28/85	35	96	--		108	—
	218	86.90	3/13/85	12/28/85	76	0	80	100% hatched	2	5
Crescent Bay	113		3/7/85			-	86	100% hatched	55	122
Thurstons	204	86.60	1/28/85	12/29/84	30	20				
	206	87.00	3/7/85	12/28/84	71	0	100	100% hatched	51	15
	207	86.90	1/28/85	12/28/84	31				found	—
	207	86.90	1/29/85	12/2/8/84	32	11.1	100	22% hatched	45	13
	208	86.00	1/29/95	1/11/85	18	0	—		80	—
	209	87.10	1/29/85	12/20/84	40	93	100	3% hatched	276	10
Big Arm	001, 003, 013, 014									
North Buswells			4/4/85			0	—	—	100	—

Appendix Table A-7. Redd counts, above and below minimum pool, at principle Flathead Lake shore spawning areas.

Location	1981 Total	1981 Above	1981 Below	1982 Total	1982 Above	1982 Below	1983 Total	1983 Above	1983 Below
Woods Bay:									
East				56	56	0	30	30	0
West Deep				110	0	110			
West Shallow	57	22	35	22	22	0	46	34	12
Yellow Bay	152	28	124	197	72	125	79	15	64
Blue Bay	45	0	45	55	0	55	45	0	45
Talking Water Creek	12	12	0	4	4	0	33	0	33
Gravel Bay	37	19	18	238	12	226	187	15	172
Dr. Richards Bay:									
North	106	106	0	45	43	2	23	23	0
South	63	63	0	15	15	0	17	17	0
Boat launch	12	12	0	27	27	0	12	12	0
Skidoo Bay:									
I	103	103	0	43	43	0	43	43	0
II				68	68	0	66	66	0
III							41	41	0
IV				15	15	0	50	50	0
Pineglen				85	85	0			
Crescent Bay	5	5	0	31	31	0	19	19	0
Lakeside				2	2	0			
Somers Bay							28	28	0
Dee Creek				16	16	0			
Total	592	370 (63%)	222 (37%)	1,029	511 (50%)	518 (50%)	719	426 (59%)	293 (41%)

APPENDIX B

KOKANEE FOOD AVAILABILITY

KOKANEE FOOD AVAILABILITY

Monitoring of Flathead Lake zooplankton populations was continued in 1984 as described by Decker-Hess and McMullin (1983). This sampling program was designed to monitor zooplankton population trends in Flathead Lake on an annual basis and to note any significant shifts in zooplankton species composition or density. A major change in the zooplankton population could have substantial effects on the kokanee salmon of the entire Flathead drainage.

RESULTS

PHYSICAL LIMNOLOGY

Average water temperatures for the upper 15 m of the water column for 1980-84 at the Bigfork station are shown in Figure B-1. The seasonal average of 9.0^{o}C in 1984 was the lowest since monitoring began in 1980. Generally, the average temperature in 1984 was up to several degrees cooler than average temperatures seen from 1980-83 except during April and May of 1982 when temperatures were 0.3^{o}C to 1.5^{o}C lower. The maximum average temperature in 1984 was 12.5^{o}C, compared to 13.6^{o}C, 14.4^{o}C, 17.9^{o}C and 15.8^{o}C from 1980-83, respectively.

Thermal stratification began in early July of 1984 and remained until late August. A deep thermocline was seen briefly in mid-October.

Secchi disc readings during 1984 ranged from 2.0 m to 11.0 m and averaged 7.7 m. Visibility was lowest from mid-May to mid-June. The 1983 average was 7.9 m.

ZOOPLANKTON

Three copepod and four cladoceran species were collected in 1984. Copepod species sampled included Epischura nevadensis, a large plankter which is predatory on smaller species. Cyclops bicuspidatus thomasi, an omnivore, and Diaptomus ashlandi, an herbivore, were the other copepod species found. The cladoceran species consisted of Leptodora kindtii, a large predator on other zooplankton, and Daphnia thorata, Daphnia longiremis, and Bosmina longirostris, all filter feeding herbivores.

The copepods Diaptomus and Cyclops comprised an average of 73.4% of the total zooplankton community sampled (excluding nauplii). The Cladocerans Daphnia spp. and Bosmina composed 26.4% of the total. Epischura and Leptodora together accounted for 0.17% of the total. These numbers are very similar to the averages seen in 1980, 1981, and 1983, but are lower than the

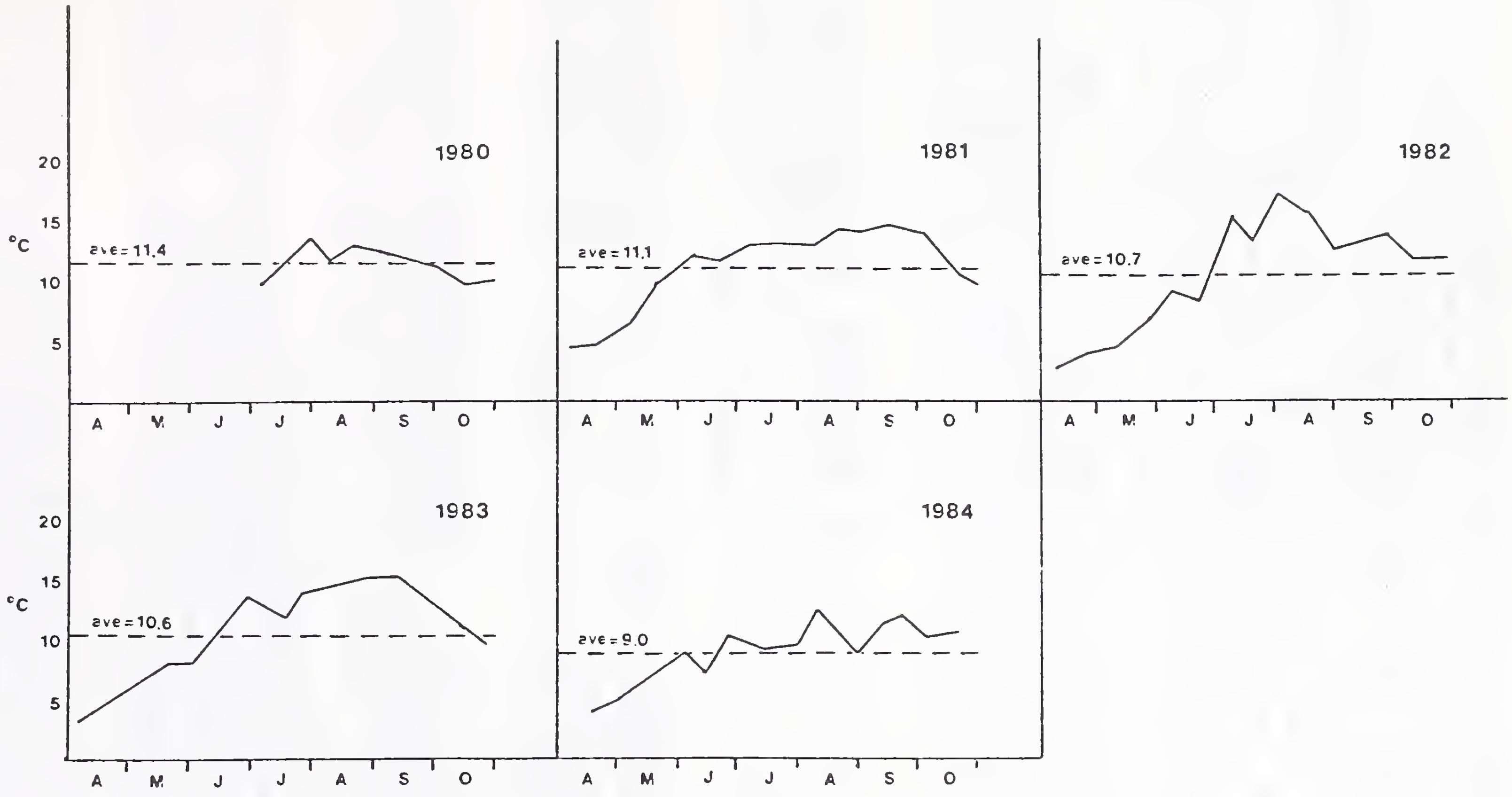


Figure B-1. Mean water temperature ($^{\circ}C$) of the surface waters (0-15 m) of Flathead Lake during 1980-84.

average seen in 1982 when copepods and cladocerans composed 87.1 and 12.9% of the total zooplankton community, respectively (Figure B-2).

Diaptomus was the most numerous organism during 1984, comprising 45.5 percent of the total number of organisms collected. This was the lowest percent composition seen since collection began in 1980 when Diaptomus accounted for 47.2 percent of the total (Table B-3). The peak density of 13.3 Diaptomus/liter appeared in late June in 1984 (Figure B-4). The peaks in 1981 and 1982 were in early June and in 1983 the peak appeared in late May. The average density of Diaptomus in 1984 was 5.22 organisms/liter, down from the 7.30/liter in 1983. Total zooplankton and Diaptomus densities were positively correlated ($r=0.88$, $p<0.0001$), showing the strong influence Diaptomus has on total zooplankton density.

Cyclops density averaged 2.64/liter in 1984, up from 1.48/liter in 1983. These organisms comprised 27.9 percent of the total zooplankton community in 1984, the greatest seasonal percentage of Cyclops since monitoring began. Two peaks were seen in Cyclops density in 1984, one in early August and one in early October (Figure B-5).

The average density of Epischura was $13.6/m^3$ (0.14/liter), down from $25.3/m^3$ (0.02/liter) in 1983. The peak density of 44.9 Epischura/m^3 occurred in the last sampling date in late October (Figure B-6). This species accounted for 0.14 percent of the total zooplankton community sampled in 1984.

Average Daphnia thorata density increased from 0.91/liter in 1983 to 1.12/liter in 1984. However, the average seasonal percent composition decreased from 11.5 percent in 1983 to 10.0 percent in 1984. The peak density of D. thorata was 4.04/liter and occurred in late June (Figure B-7).

Average density of Daphnia longiremis increased from 0.15/liter in 1983 to 0.31/liter in 1984 (Table B-3) and this species comprised 2.3% of the total zooplankton community during 1984. The peak density was in late June (Figure B-8).

Unidentified Daphnia accounted for 3.2% of the zooplankton total in 1984. their average density was 0.35/liter. This is the first year in which unidentifiable Daphnia have been used in the density and average percent composition totals. Previously the unidentified Daphnia were proportionately added to D. thorata and D. longiremis totals.

Bosmina density peaked at 3.41/liter in early June (Figure B-9). The average density of Bosmina in 1984 was 1.21/liter. The average percent composition in 1984 was 10.9 percent, an increase over the 8.6 percent found in 1983. The 1984 figure surpasses the 1983 number as the highest Bosmina percentage seen since sampling began in 1980.

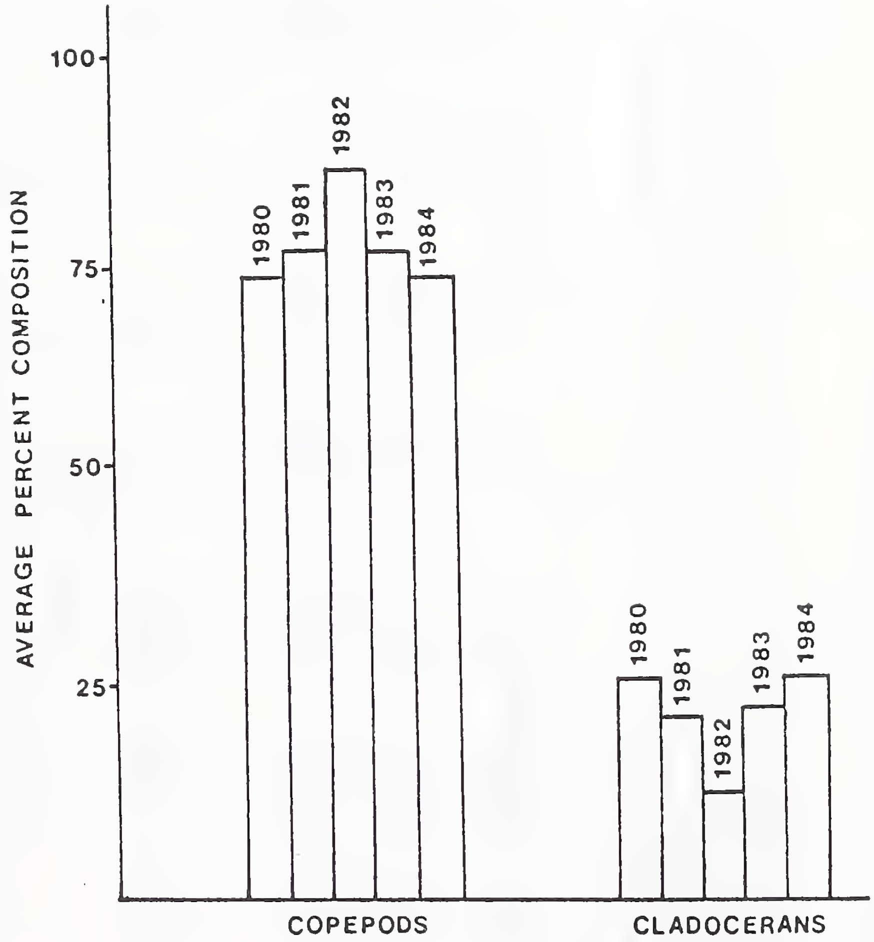


Figure B-2. Comparison of zooplankton composition by percent of Cladocera and Copepod in the surface waters (0-15 m) of Flathead Lake during 1980-84.

Figure B-3. The average percent composition and density of zooplankton species colected from the Bigfork station of Flathead Lake during 1980-84. All densities are number per liter except <u>Epischura</u> and <u>Leptodora</u>, which are number per cubic meter.

	Average percent composition					Density				
	80	81	82	83	84	80	81	82	83	84
Diaptomus	47.2	54.4	68.5	60.7	45.5	8.23	11.25	17.65	7.30	5.22
Cyclops	26.6	22.8	18.6	16.4	27.9	3.34	3.23	3.17	1.48	2.64
Epischura	<1.0	<1.0	<1.0	0.28	0.14	25.3	51.1	—	23.30	13.64
D. thorata	16.0	14.5	8.9	11.5	10.0	2.03	2.27	1.47	0.91	1.12
D. longiremis	4.4	0.8	0.09	1.8	2.3	0.89	0.20	0.02	0.15	0.31
Unidentified Daphnia	—	—	—	—	3.2	—	—	—	—	0.35
Bosmina	5.7	7.5	3.9	8.6	10.9	0.74	1.48	0.65	0.96	1.21
Leptodora	<1.0	<1.0	<1.0	0.08	0.03	31.0	9.9	—	6.4	3.60
					Total	15.3	18.5	23.0	10.9	10.9

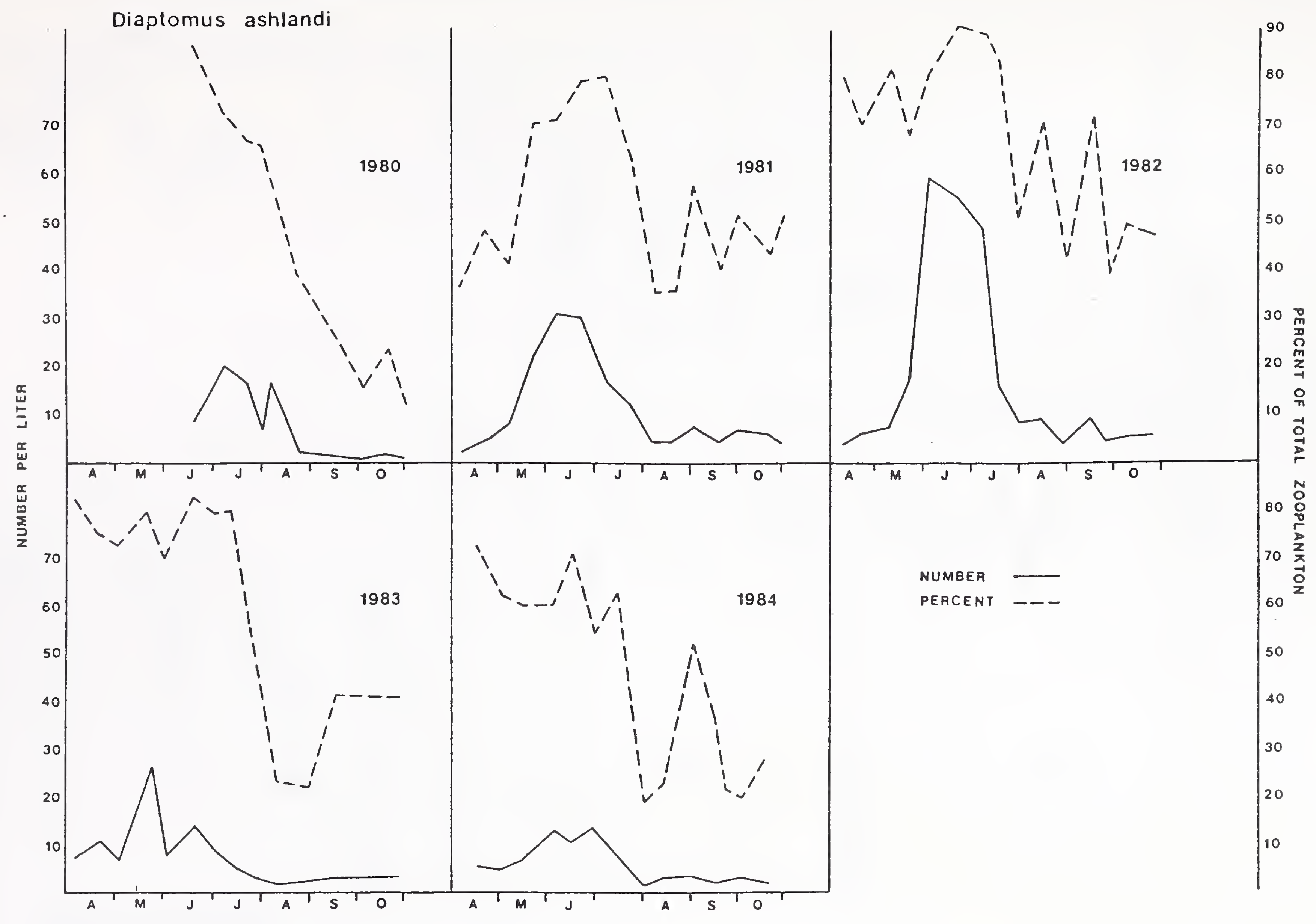


Figure B-4. Seasonal density trends (no./1) Diaptomus ashlandi in the srface waters (0-15 m) of Flathead Lake during 1980-84.

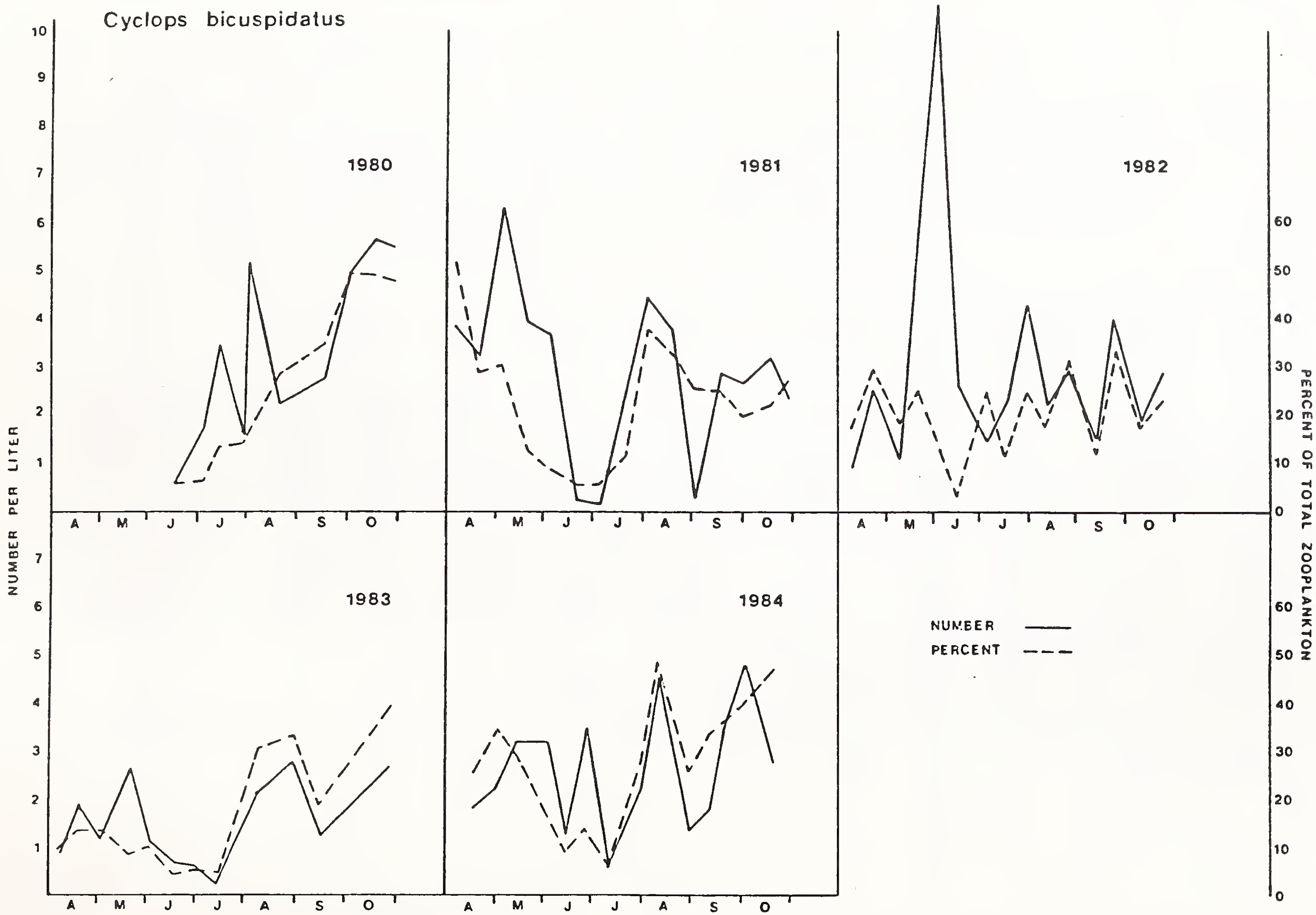


Figure B-5. Seasonal density trends (no./1) <u>Cyclops</u> <u>bicusppidatus</u> in the surface waters (0-15 m) of Flathead Lake during 1980-84.

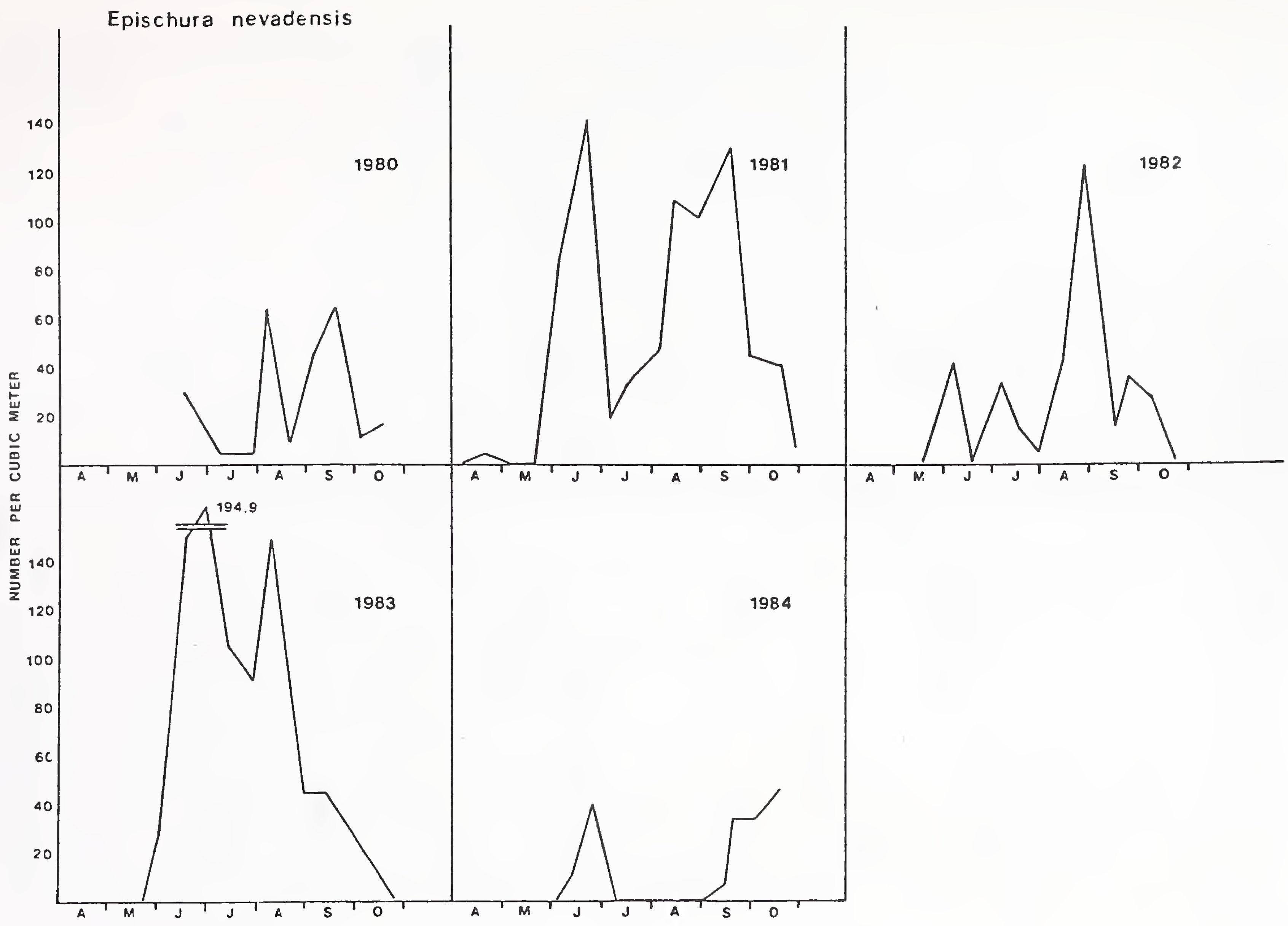


Figure B-6. Seasonal density trends (no./m^3) of Epischura nevadensis in the surface waters (0-15 m) of Flathead Lake during 1980-84.

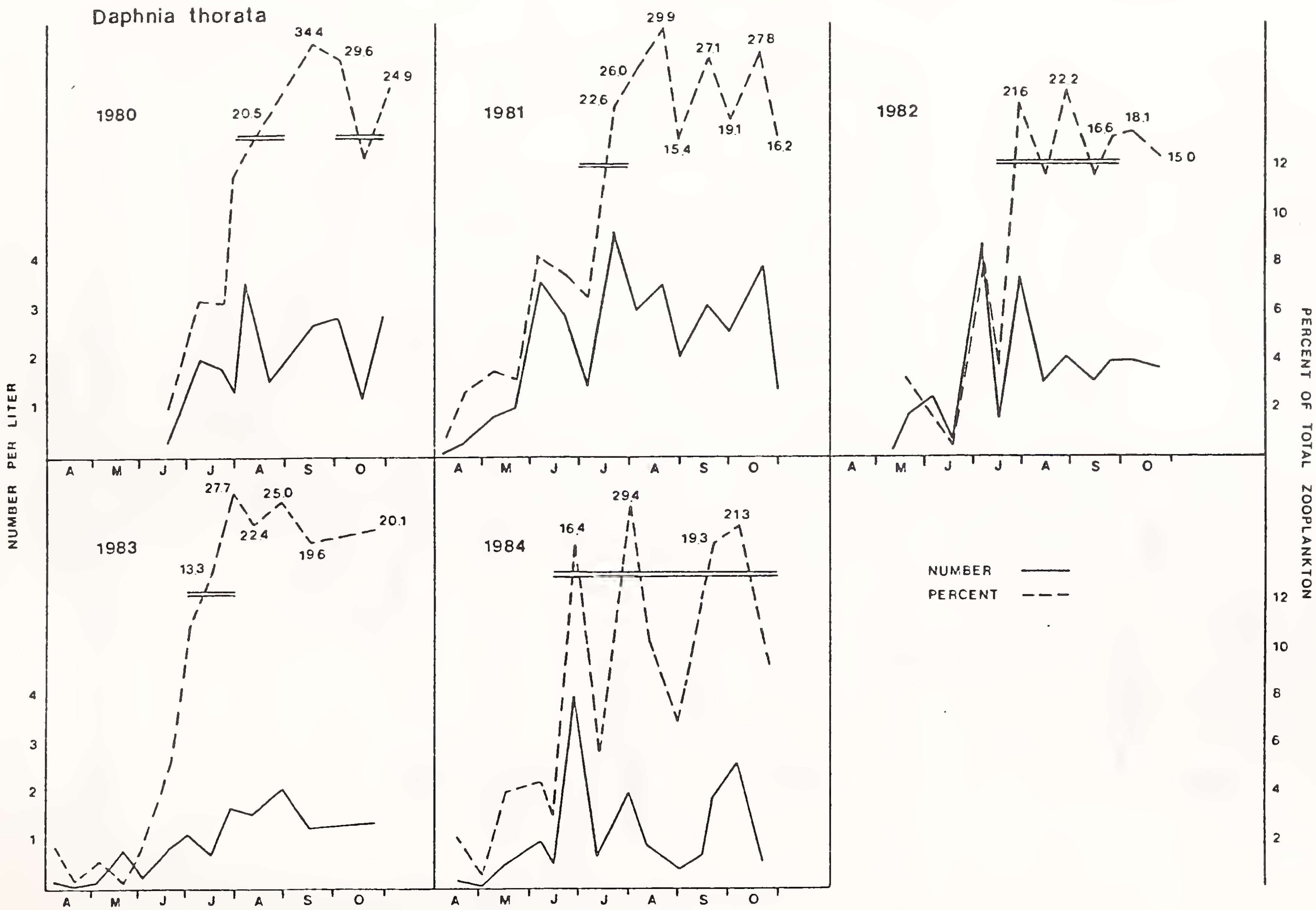


Figure B-7. Seasonal density trends (no./l) of Daphnia Thorata in the surface waters (0-15 m) of Flathead Lake during 1980-84.

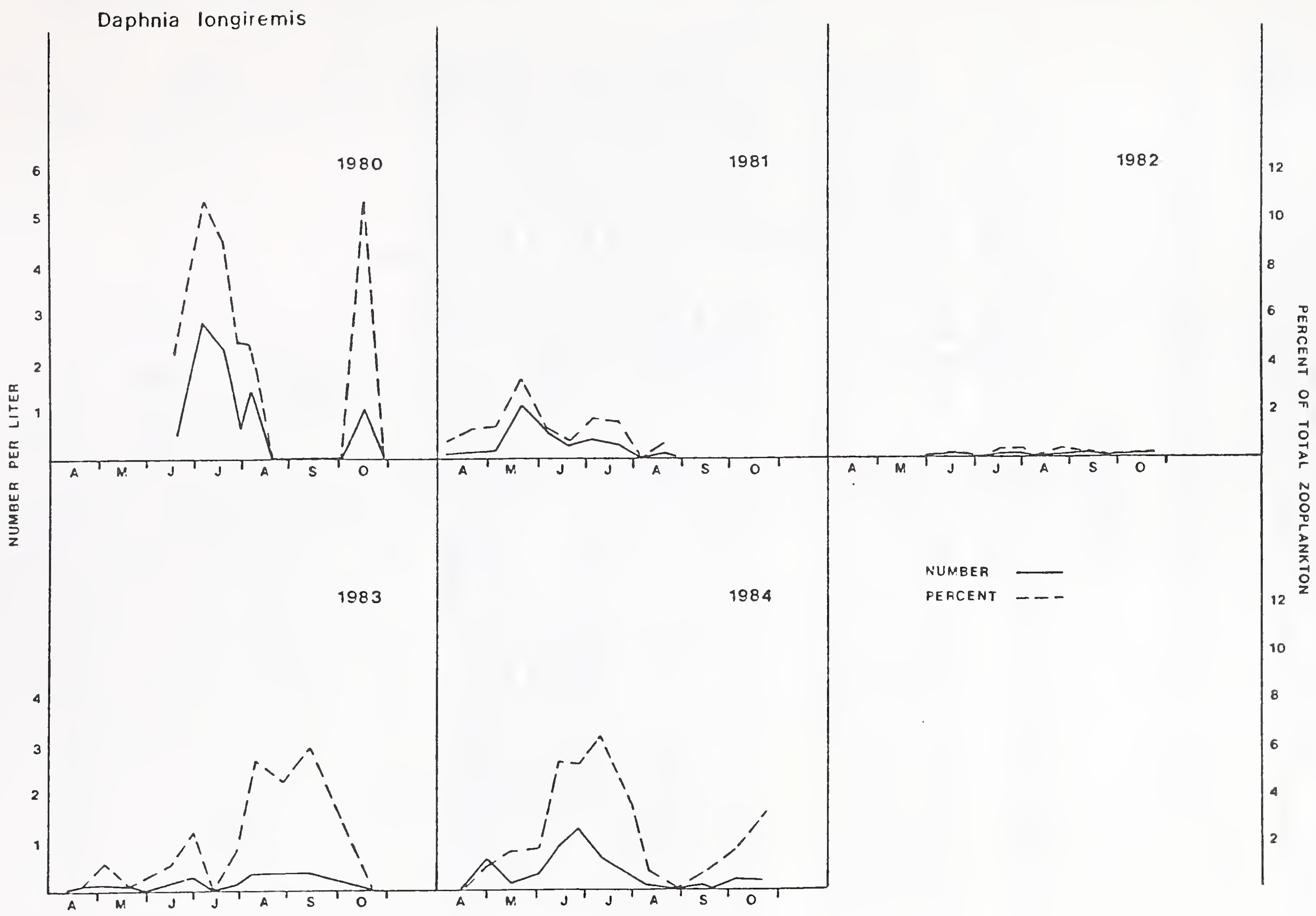


Figure B-8. Seasonal density trends (no./l) of <u>Daphnia</u> <u>logniremis</u> in the surface waters (0-15 m) of Flathead Lake during 1980-84.

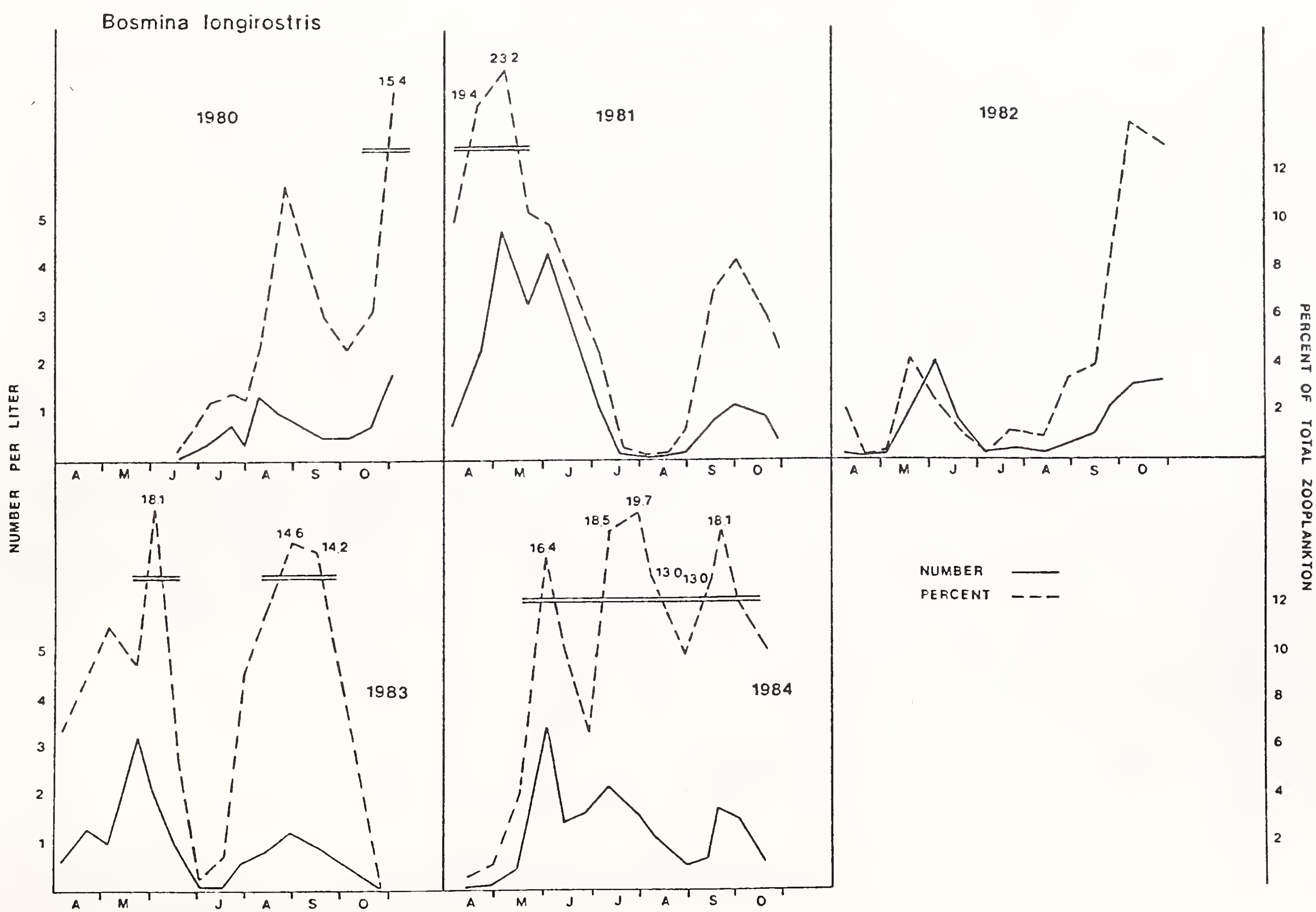


Figure B-9. Seasonal density trends (no./l) of <u>Bosmina</u> <u>longirostris</u> in the surface waters (0-15 m) of Flathead Lake during 1980-84.

Leptodora appeared in the samples at similar times in 1982 and 1984 (Figure B-10), however the average density decreased from 6.40/m^3 (0.006/liter) in 1983 to 3.60/m^3 (0.004/liter) in 1984. *Leptodora* comprised 0.03 percent of the zooplankton sample in 1984.

The average number of plankters in 1984 was 10.9/liter (excluding nauplii), identical to the density found in 1983.

DISCUSSION

Of the four species identified by Leathe and Graham (1982) to be important food items for kokanee, three decreased in density and one increased between 1983 and 1984.

Leathe and Graham (1982) found that *Daphnia thorata* was the most important food item in the diet of all kokanee size classes, comprising 70-90 percent of the food biomass. Age III+ and older kokanee used *Diaptomus* during the winter when preferred prey species were absent, and *Leptodora* and *Epischura* were important food items when available during the summer and fall.

Although the temperature was consistently cooler in 1984 than in previous years, light penetration was very similar to 1983 and total zooplankton density was virtually identical, though some individual species densities changed. No temporal displacement of *Daphnia* and *Bosmina* or change in species composition of *Daphnia* has been documented. Rieman and Falter (1981) associated these types of changes with the establishment of *Mysis relicta* in Lake Pend Oreille, Idaho. *Mysis* has been present in Flathead Lake since 1981, but to date no effects on the zooplankton community structure or seasonal abundance patterns has been observed. Monitoring of Flathead Lake zooplankton densities and composition will continue to identify the effects of *Mysis* and other environmental changes on the kokanee food supply.

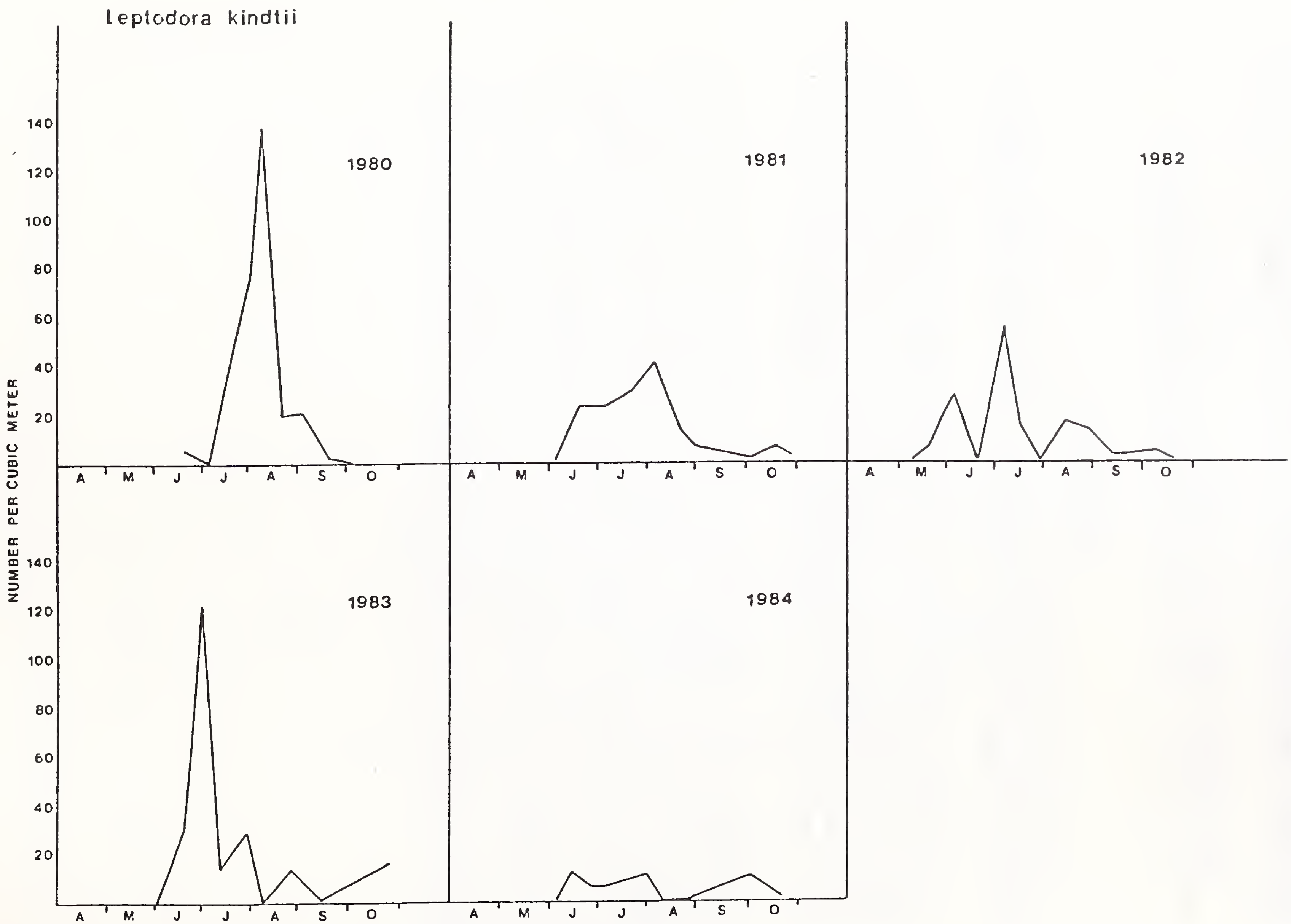


Figure B-10. Seasonal density trends (no./m^3) of *Leptodora kindtii* in the surface waters (0-15 m) of Flathead Lake during 1980-84.

APPENDIX B
LITERATURE CITED

Decker-Hess, Janet and Steve L. McMullin. 1983. Impacts of water level fluctuations on kokanee reproduction in Flathead Lake. Montana Department of Fish, Wildlife and Parks. 172 pp.

Leathe, S.A. and P.J. Graham. 1982. Flathead Lake fish food habits study - Final Report. Montana Department of Fish, Wildlife and Parks, Kalispell. 137 pp.

Rieman, B.E. and C.M. Falter . 1981. Effects of the establishment of <u>Mysis relicta</u> on the macrozooplankton of a large lake. Transactions of the American Fisheries Society. 110:613-620.

APPENDIX C

STUDIES OF THE DISPERSAL AND SPAWNING DESTINATION OF THE WINTER KOKANEE AGGREGATION IN SKIDOO BAY, FLATHEAD LAKE

SKIDOO BAY TAGGING STUDIES

In recent years a concentrated fishery for kokanee has developed in Skidoo Bay during winter and early spring. When the bay has frozen, the ensuing ice fishery has been shown to harvest a large number of primarily age III+ kokanee (Graham and Fredenberg, 1982). This tagging study was initiated to determine the spawning destination(s) of the Skidoo Bay winter aggregation and follow their movements during the preceding spring and summer. It is not known why kokanee school in Skidoo Bay during the winter in such abundance.

ANGLER RETURNS

Marked fish were recovered from the early spring fishery in Skidoo Bay, throughout the lake during the summer, and in the Flathead River fishery in the fall (Table C-1). We also observed tagged fish during spawning surveys. A disproportionately low number of red tags were recovered leading to speculation that this group suffered high tagging mortality.

Seventeen tagged kokanee were taken by anglers from Skidoo Bay from 17 March to 15 April prior to their movement out of the bay (Table C-1 and Figure C-2). One blue tagged kokanee was returned from the stomach of a lake trout caught by an angler during this time. Catch rates of each color appeared to be related to their date of capture. The earlier tagged fish were captured at twice the rate of the later tagged groups.

Eighty-three tags were returned by summer anglers from 13 May through 3 September. Two percent of the fish tagged in Skidoo Bay were returned by cooperating anglers. All but two of the summer returns were from anglers fishing in Flathead Lake. One tagged kokanee was returned from the stomach of a bull trout, and one was returned by a river angler 13 July. The tags returned were proportional between three of the colors, indicating a mixing of the Skidoo Bay kokanee concentration throughout the lake fishery. Less than one percent of the red tags were returned by cooperating anglers.

The first tagged fish returned was caught on 7 June near Wildhorse Island. The last tagged fish reported from the lake was caught on 3 September near the river mouth prior to the kokanee's ascent into the river system for their spawning migration.

The majority of the tagged fish returned were captured in July (47%). Twenty-seven percent of the tagged fish were caught in June, 20 percent in August, and only 6 percent in September. It is not known if the overall temporal distribution was a result of angler preference or fish distribution.

Table C-1. Date, number tagged and number and percent tags returned by anglers from the purse seining/tag return effort from Skidoo Bay in February and March, 1984.

Tag Color	Date Tagged	Number Tagged	Skidoo Bay 03/17-04/15 #	Skidoo Bay 03/17-04/15 %	Flathead Lake 06/08-09/03 #	Flathead Lake 06/08-09/03 %	Flathead River 09/08-09/19 #	Flathead River 09/08-09/19 %	Total #	Total %
			Number and Percent Return By Anglers							
Yellow	2/27	975	6	.62	19	1.9	8	.82	34	3.5
Red	2/27	543	3	.55	3	.55	0	0	5	.9
Blue	3/15	1,887	6	.32	38	2.1	14	.74	58	3.1
Orange	3/24	1,120	2	.18	23	2.1	6	.54	31	2.8
Totals		4,525	17	.38	83	2.0*	28	.70	128*	3.1

* Red tags were not included in the average due to suspected mortality.

Figure C-2 Temporal distribution of tags returned from kokanee salmon in Flathead Lake and River from March through September 1984.

Although fishing was occurring throughout the lake in June, orange tagged fish were caught only from the Wildhorse Island area. No blue tags were returned in September, but there was no indication that this absence was due to an earlier movement into the river system.

Although the percentage return of each color of tag varied by area, the majority of each color was harvested from three of the major fishing areas: Bigfork-Woods Bay area, Wildhorse Island, and Lakeside (Figure 15). Eight of the twelve tagged fish returned from Lakeside, were yellow recaptures. The only month kokanee were returned from Big Arm Bay was in June. Kokanee move out of shallow water as summer water temperature increases (Hanzel, pers. comm.) The Bigfork area was the only location where tagged fish were caught in September.

An additional 28 tags were returned by river anglers during the kokanee spawner lure fishery in September. The first tagged fish captured in the river system during the fall occurred on 8 September in the "Salmon Hole", 20 miles upstream of the lake. Tag returns continued from the same area until the river fishery closure on 20 September. Returned tags from the "Salmon Hole" were proportional for three of the four colors. The only tag color not represented in the returns was red.

SPAWNING DISTRIBUTION

Tagged kokanee were observed by divers or collected by gill nets, fish traps or seines from major spawning areas in the Flathead system. Based on these observations, it appears that the Skidoo Bay winter kokanee concentration originates from most major spawning stocks. Three percent of each of the blue, yellow and orange tagged fish were observed during maximum or total counts during the spawning period. Only one red tagged fish was observed during the spawning period.

Maximum or total counts of 134 tags were observed in seven river spawning areas including 117 tags in McDonald Creek , 6 in the main stem Flathead , 5 in the Middle Fork Flathead (some of these were probably on their way to McDonald Creek), 2 in the South Fork Flathead and 1 in Brenneman's Slough (Figure C-3). No tags were observed in the Whitefish River. It was felt water clarity in the Whitefish River prevented accurate observations of tags. Tagged kokanee were first observed in McDonald Creek on 5 September. The last tagged kokanee was observed on 7 December in the main stem Flathead.

Three blue tagged kokanee were retrieved from seine hauls at Hatchery Bay and one from a gill net set at Woods Bay. Two blue tagged kokanee were also observed in the Swan River at Bigfork Dam and one at the Bigfork Dam powerhouse. The appearance of only blue

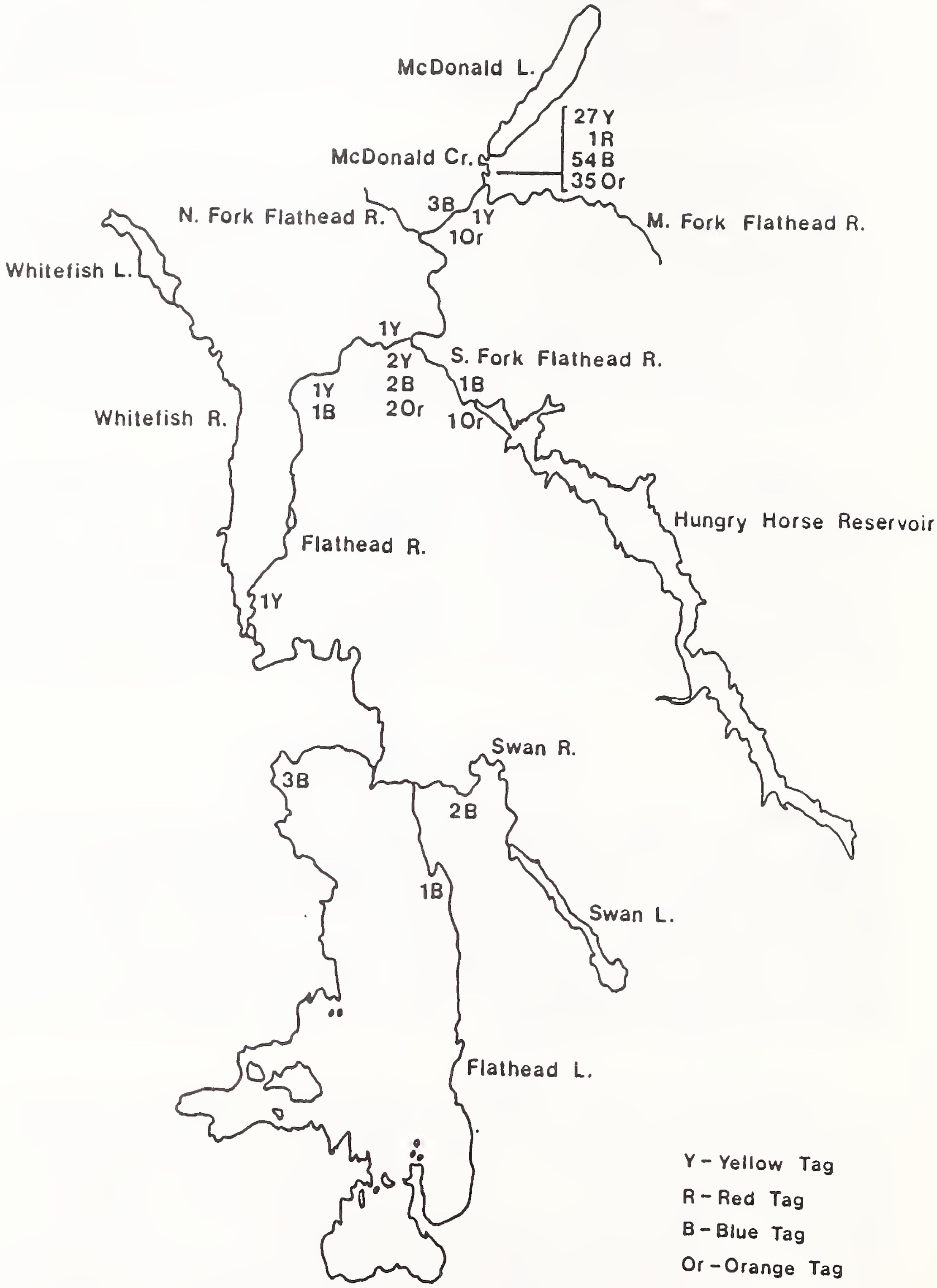


Figure C-3. Location of all tags observed or returned during the spawning period in Flathead River and Lake, October through December, 1984.

tagged kokanee in these areas may be a function of preference or a result of the greater number of blue tags compared to yellow or orange. Although 90% of shoreline spawning occurs south of Yellow Bay, no tagged fish were found.

In summary, kokanee that winter in Skidoo Bay dispersed throughout Flathead Lake during the summer, into the river in the fall, and were observed at eleven spawning areas in the river, its tributaries, and around the lakeshore. Of the 140 tagged fish observed during the spawning period, 117 (84%) were in McDonald Creek, 5 (3.5%) in the Middle Fork, 2 (1.4%) in the South Fork, and 11 (7.8%) in the main stem Flathead River. No tagged fish were observed in Skidoo Bay spawning area. The distribution of tagged fish in the Flathead River system was proportional to the overall distribution of spawners (Clancey and Fraley, 1985).

Tag returns from the spring fishery suggested that kokanee held in Skidoo Bay through April. Tag returns from the lake fishery in June showed that fish had dispersed west to Big Arm and Wildhorse Island, and as far north as Somers, Woods Bay, and Bigfork. Tag returns are perhaps as strongly related to the distribution of fishing effort as to the distribution of the fish, but they suggest that kokanee disperse rapidly in May throughout the lake.

APPENDIX C
LITERATURE CITED

Clancey, Pat and J. Fraley. 1985. Effects of the operation of Kerr and Hungry Horse Dams on the kokanee fishery in the Flathead River system. Completion Report to BPA.

Graham, P.J. and W. Fredenberg. 1982. Flathead Lake fisherman census, U.S. Environmental Protection Agency. Montana Department Fish, Wildlife and Parks, Kalispell, Montana.

APPENDIX D

Method for measuring hydraulic conductivity of
beach aquifers, using a sandpoint well

from
Woessner, W.W. and Brick, C.M., 1983

Groundwater Investigations related to the location
and success of kokanee salmon spawning, Flathead Lake, Montana:

Preliminary results
April 1982 - June 1983
University of Montana, Missoula, MT

III. Standpipe Test

A pump test utilizing the Mark VI Groundwater Standpipe developed by Terhune (1958) was used at each site to obtain a value for hydraulic conductivity. The standpipe apparatus, shown in Figure A-1, consists of a length of 3.2 cm diameter pipe with a driving point and 5.1 cm of perforations at the lower end. The pipe is driven approximately halfway into the gravel and is then cleaned out by pumping and surging and allowed to equilibrate. The suction apparatus consists of a converted tire pump with a reversed piston and a calibrated collection cylinder. It has a length of narrow pipe with centering lugs attached to it which can be lowered into the standpipe. The narrow pipe is lowered a known distance (usually between 0.6 cm and 2.5 cm below the measured water elevation in the standpipe and is held in that position by an adjustable bracket. the first step in the testing procedure is to calculate the volume of water which must be removed from the standpipe to lower the head the calibrated distance to the tip of the suction tubing. Pumping is started and the time it takes to remove this volume of water is noted. Pumping continues and maintains the 0.6 to 2.5 cm drop in head in the standpipe. Pumping stops before the collection chamber is filled and the time and volume of water are noted. Time and volume are then corrected by subtracting the amounts necessary to initially drop the head.

These data are used in an adaptation of Darcy's law: $K=Q/AH$ in which K is the hydraulic conductivity, Q is the corrected volume of water pumped in the time interval, H is the suction head applied and A is a constant which is a function of the area and geometric shape of flow into the standpipe (Donnan, Asce and Aronovici, 1961).

The A-function was calculated for the standpipe according to the method described by Kadir (1955). The value for A in dimensions of length is taken from graphs presented by Kadir and is dependent on the ratios L/d, S/L, and D/d where d is the diameter of the standpipe, D is the distance from the water table to the submerged end of the standpipe, L is the length of the perforated section and S is the distance from the end of the standpipe to the impermeable lower boundary. Since the standpipe was emplaced less than a foot in the gravels and since the depth to the impermeable boundary is unknown, but assumed to be very large in comparison with L, the value for S was assumed to be infinity.

Calculations are shown below:

A-function: D/d = 8.12
L/d = 1.23
S/L = infinity

From Figures 11 and 12 in Kadir (1955) A = 7.15'

Permeability: $K = Q/(AH)$ (English units with metric conversion)

Skidoo Bay: $K = 9.76\ in^3/min/(7.15")(1") = 1.36$ in/min = 207 cm/hr

Pineglen: $K = 52.89\ in^3/min/(7.15")(1/2") = 14.79$ in/min = 2255 cm/hr

Hochmark's: $K = 3.05\ in^3/min/7.15")(1/2") = 0.43$ in/min = 65.5 cm/hr

Dr. Richard's South: $K = 20.57\ in\ ^3/min/(7.15")(1/2") =$

5.75 in/min = 876 cm/hr

Crescent Bay: $K = 17.90\ in^3/min/(7.15")(1/4") =$

10.01 in/min = 1524 cm/hr

APPENDIX D
LITERATURE CITED

Donnan, W.W., F. Asce, V.S. Aronovici, 1961. Field measurement of hydraulic conductivity. Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers., IR 2, 13 pp.

Kadir, N. A., 1955. Measurement of permeability of saturated soils below the water table. Ph.D. Dissertation, Utah State University, Logan, Utah.

Terhune, L.D.B., 1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. J. Fish Res. Bd. Canada, 15(5), pp. 1027-1063.

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